Empson, R. A; Miskelly, C. M. 1999. The risks, costs and benefits of using brodifacoum to eradicate rats from Kapiti Island, New Zealand. *New Zealand Journal of Ecology* 23: 241-254.

Ford, R. G. 2002. *Command Bird Injury Report*, Appendix B, Estimated Common Murre and Marbled Murrelet Mortality Resulting from the T/V *Command* Spill, *R.G. Ford Consulting Co.*, April 30, 2002.

Godfrey, M. E. R. 1985. Non-target and Secondary Poisoning Hazards of 'Second-generation' Anticoagulants. *Acta Zoologica Fennica* 173: 209-212.

Hamilton, S. 1998a. A test of burrow occupancy of Sooty Shearwaters (*Puffinus griseus*) using chick response to sound. *Notornis* 45: 64-66.

Hamilton, S. 1998b. Determining burrow occupancy, fledging success and land-based threats to mainland and near-shore island sooty shearwater (*Puffinus griseus*) colonies. *New Zealand Journal of Zoology* 25(4): 443-453.

Hamilton, S.; Cruz, J. ; Fletcher, D.; Hunter, C.; Moller, H. 1997. Reliability of an infra-red scope for assessing sooty shearwater burrow occupancy: a pilot study. *University of Otago Wildlife Management Report* No. 88. 23 pp.

Hamilton, S.; J. Cruz; Hunter, C.; Moller, H. 1998. An infrared scope for assessing sooty shearwater burrow occupancy. *Conservation Advisory Science Notes* 187: 1-19.

Hamilton, S. A.; Moller H. 1995. Can PVA models using computer packages offer useful conservation advice? Sooty Shearwaters in New Zealand as a case study. *Biological Conservation* 73: 107 - 117.

Hamilton, S.; Moller, H.; Charteris, M.; Cooper, W. 1996. Breeding colonies of Sooty Shearwater (*Puffinus griseus*) on Whenua Hou, Codfish Island, *University of Otago Wildlife management Report* No 77. 49 pp.

Hamilton, W. J; Moller, H. 2000. Use of brodifacoum and cyanide poisons to control introduced small mammals in New Zealand forests brings net conservation benefit. *Ecosystems Consultants Report No.* 17. 36 pp.

Hawke, D.; Newman, J. 2001. Tītī feed plants as well as their chicks. Poster Abstract in: Howard, M. & H. Moller (Eds.). *He Minenga Whakatū Hua o Te Ao* 'Sustaining the fruits of the land'. Proceedings of a hui, Murihiku Marae 25 - 27 August 2000. Online at: http://www.otago.ac.nz/Zoology/hui

Howard, M.; Moller, H. (Eds.) 2001. *He Minenga Whakatū Hua o Te Ao* 'Sustaining the fruits of the land'. Proceedings of a hui, Murihiku Marae 25 - 27 August 2000. Online at: http://www.otago.ac.nz/Zoology/hui

Hunter, C. M.; H. Moller; Fletcher, D. 2000a. Parameter uncertainty and elasticity analyses of a population model: setting research priorities for shearwaters. *Ecological Modelling* 134(2-3): 299-323.

Hunter, C.M.; Moller, H.; Kitson, J. 2000b. Muttonbirder selectivity of Sooty Shearwater (Tītī) chicks harvested in New Zealand. *New Zealand Journal of Zoology*. 27: 395 - 414.

Jones, C. 2000. Sooty shearwater (*Puffinus griseus*) breeding colonies on mainland South Island, New Zealand: evidence of decline and predictors of persistence. *New Zealand Journal of Zoology* 27: 327-334.

Jones, C.; Bettany, S.; Moller, H.; Fletcher, D.; Lyver, P.; de Cruz, J. (in press). Burrow occupancy and productivity at coastal sooty shearwater (*Puffinus griseus*) breeding colonies, South Island, New Zealand: can mark-recapture be used to estimate burrowscope accuracy? *Wildlife Research.*

King, C.M. (Ed.) 1990. *Handbook of New Zealand mammals.* Oxford University Press.

Lyver, P. O'B. 2000. Identifying mammalian predators from bite marks: a tool for focusing wildlife protection. *Mammal Review* 30(1): 31-43.

Lyver, P. O'B. 2002. Use of traditional knowledge by Rakiura Māori to guide Sooty Shearwater harvests. *Wildlife Society Bulletin.* 30(1):29-40.

Lyver, P. O'B.; Hamilton, S.A.; Mc Kenzie, M.; Dickson, I.; Dooher,T.; Broad, T.; Moller, H. 1998. A Burrowscope for examining petrel nests in burrows. *Conservation Advisory Science Notes:* 209: 21 pp.

Lyver, P. O'B.; Moller, H. 1999. Tītī harvests by Rakiura Māori: a case study of the use of Māori Traditional Environmental Knowledge for sustainable natural resource management. *Proceeding of Landcare Conference, Wellington, New Zealand, Landcare Research Web page.* www.landcare.cri.nz/conferences/manaakiwhenua/papers/index.shtml?Lyver

Lyver, P. O'B; Moller, H.; Thomson, C. 1999. Changes in sooty shearwater *Puffinus griseus* chick production and harvest precede ENSO events. *Marine Ecology Progress Series* 188: 237-248.

Lyver, P. O'B.; Robertson, C. J. R.; Moller, H. 2000. Predation at Sooty Shearwater (*Puffinus griseus*) Colonies on the New Zealand Mainland: is there safety in numbers? *Pacific Conservation Biology* 5: 347-357.

McClelland, P. 1999. The likely impact of a brodifacoum drop on non-target species on Campbell Island. Unpublished report on DoC file SUB 30 Invercargill.

Moller, H. 2001. Co-management of a bicultural research project: a research provider's perspective. In: Howard, M. & H. Moller (Eds.). *He Minenga Whakatū Hua o Te Ao* 'Sustaining the fruits of the land'. Proceedings of a hui, Murihiku Marae 25 - 27 August 2000. Online at: http://www.otago.ac.nz/Zoology/hui

Moller, H. 2002. Tītī harvests at Taukihepa, 1958 – 1983. Unpublished University of Otago report to manu owner. 66 pp.

Moller, H. In press. Are current harvests of seabirds sustainable? *Acta Zoologica Sinica*

Moller, H.; Cruz, J. de.; Fletcher, D.; Garrett, K.; Hunter, C.; Jones, C.J.; Kitson, J.; Lyver, P.; Newman, J.; Russell, B.; Scofield, P.; Scott, D. 1999. Kia Mau Te Tītī Mo Ake Tōnu Atu: goals, design and methods. *University of Otago Wildlife Management Report* Number 117. 76 pp.

Moller, H.; Horsley, P.; Lyver, P. O'B.; Taiepa, T.; Davis, J.; Bragg, M. 2000. Co-management by Māori and Pakeha for improved conservation in the 21st century. Pp 156 – 167 In: Perkins, H. & Memon, A. (eds.) *Environmental Planning and Management in New Zealand.* Dunmore Press, Palmerston North.

Moller, H.; Newman, J.; Scott, D.; Fletcher, D. 2002a. A Survey of Tītī Abundance and Harvest Intensity on the Bragg manu, Tia Island. *University of Otago Wildlife Management Report:* Number 801-2.

Moller, H.; Newman, J.; Scott, D.; Fletcher, D. 2002b. A Survey of Tītī Abundance and Harvest Intensity on the Campbell manu, Ernest Island. *University of Otago Wildlife Management Report:* Number 801-11.

Newman, J. 2001. An amazing old bird. *Tītī Times* No. 9 (November 2001), p 3.

Newman, J.; Russell, D.; Scott, D.; Fletcher, D.; Moller, H. 2002a. A Survey of Tītī Abundance and Harvest Intensity on manu Maaka Horomanupatu, Murderer's Cove, Taukihepa. *University of Otago Wildlife Management Report:* Number 801-4.

Newman, J.; Scott, D.; Fletcher, D.; Moller, H. 2000b. A Survey of Tītī Abundance and Harvest Intensity on the Young manu, Tia Island. *University of Otago Wildlife Management Report*: Number 801-1. 20 pp.

Newman, J.; Scott, D.; Moller, H; Fletcher, D. 2002c. A Survey of Tītī Abundance and Harvest Intensity on Pukeweka Island. *University of Otago Wildlife Management Report*: Number 801-10.

Newman, J.; Scott, D.; Söhle, I.; Moller, H.; Fletcher, D. 2002d. A Survey of Tītī Abundance and Harvest Intensity on Pikomamakunui Island. *University of Otago Wildlife Management Report*: Number 801-6.

Newman, J.; Scott, D.; Uhlmann, S.; Fletcher, D.; Moller, H. 2002e. A Survey of Tītī Abundance and Harvest Intensity on Manuaroto manu, Murderer's Cove, Taukihepa. *University of Otago Wildlife Management Report*: Number 801-3.

Oedekoven, C. S.; Ainley, D. G.; Spear, L. B. 2001. Variable responses of seabirds to change in marine climate: California Current, 1985 - 1994. *Marine Ecology Progress Series* 212: 265-281.

Ogilvie, S.C.; Pierce, R.J.; Wright, G.R.G.; Booth, L.H.; Eason, C.T. 1997. Brodifacoum residue analysis in water, soil, invertebrates, and birds after rat eradication on Lady Alice Island. *New Zealand Journal of Ecology* 21 (2): 195-197.

Paine, R.T. 1994. *Marine rocky shores. An experimentalist's perspective.* Nordbruite: Ecology Institute.

Pierce, R. J. 1995. The Impact of Kiore on Pycroft's Petrels and Little Shearwaters. Department of Conservation Science and Research Investigation Summary 1994-1995.

Richdale, L.E. 1963. The biology of the sooty shearwater, *Puffinus griseus*. *Proceedings of the Zoological Society of London*. 141: 1 - 117.

Robertson, H. A.; Colbourne, R. M.; Nieuwland, F . 1993. Survival of Little Spotted Kiwi and Other Forest Birds Exposed to Brodifacoum Rat Poison on Red Mercury Island. *Notornis* 40: 253-262.

Scofield, R. P.; Christie, D. 2002. Beach patrol records indicate a substantial decline in sooty shearwater (*Puffinus griseus*) numbers. *Notornis* 49: 158-165.

Scofield, R. P.; Fletcher, D. J.; Robertson, C.J.R. 2001. Tītī (sooty shearwaters) on Whero Island: Analysis of historic data using modern techniques. *Journal of Agricultural, Biological, & Environmental Statistics*. 6(2): 268-280.

Scott, D.; Newman, J.; Fletcher, D.; Charleton, K.; Moller, H. 2002a. A Survey of Tītī Abundance and Harvest Intensity on Parata manu, Murderer's Cove Taukihepa. *University of Otago Wildlife Management Report:* Number 801-5.

Scott, D.; Newman, J.; Fletcher, D.; Charleton, K.; Moller, H. 2002b. A Survey of Tītī Abundance and Harvest Intensity on Pohowaitai Island. *University of Otago Wildlife Management Report:* Number 801-7.

Scott, D.; Newman, J.; Uhlmann, S.; Fletcher, D.; Moller, H. 2002c. A Survey of Tītī Abundance and Harvest Intensity on Betsy Island. *University of Otago Wildlife Management Report:* Number 801-9.

Scott, D.; Newman, J.; Uhlmann, S.; Fletcher, D.; Moller, H. 2002d. A Survey of Tītī Abundance and Harvest Intensity on Waitakua manu, Taukihepa. *University of Otago Wildlife Management Report:* Number 801-8.

Serventy, D. L.; Curry, P. J. 1984. Observations on colony size, breeding success, recruitment and inter-colony dispersal in a Tasmanian colony of short-tailed shearwaters *Puffinus tenuirostris* over a 30 year period. *Emu* 84: 71 - 79.

Stewart-Oaten, A.; Murdoch, W. W.; Parker, K. R. 1986. Environmental impact assessment: psudoreplication in time? *Ecology* 67:929–940.

Taylor, G. A. 1986. *The ecology of Norway rats on Campbell Island.* Unpublished Report, Ecology Division, DSIR, Nelson.

Taylor, G. A. 2000a: Action plan for seabird conservation in New Zealand. Part A, Threatened seabirds. *Threatened Species Occasional Publication No 17:* Pp 1–234. Wellington, Department of Conservation.

Taylor, G. A. 2000b: Action plan for seabird conservation in New Zealand. Part B, Non-Threatened seabirds. *Threatened Species Occasional Publication No 17.* Pp 237–435. Wellington, Department of Conservation.

Taiepa, T.; Lyver, P.; Horsley, P.; Davis, J.; Bragg, M.; Moller, H. 1997. Co-management of New-Zealand's conservation estate by Mäori and Pakeha: a review. *Environmental Conservation* 24(3): 236-250.

Towns, D. R. 1991. Response of Lizard Assemblages in the Mercury islands, New Zealand to Eradication of an Introduced Rodent: the Kiore *(Rattus exulans). Journal of the Royal Society of New Zealand* 21: 119-156.

Towns, D. R. 1996. Changes in Habitat Use By Lizards on a New Zealand Island Following Eradication of the Introduced Pacific Rat *(Rattus exulans)*. *Pacific Conservation Biology* 2: 286-292.

Towns, D.R.; Atkinson, I.A.E.; Daugherty, C.H. 1990. The potential for ecological restoration in the Mercury Islands. Pp 91-108. In: Towns, D.R.; Daugherty, C.H.; Atkinson, I.A.E. (Eds.). *Ecological restoration of New Zealand islands.* Conservation Sciences Publication No. 2, Department of Conservation, Wellington.

Uhlmann, S. S. 2001. *Accidental take of Sooty (Puffinus griseus) and Short-tailed Shearwaters (P. tenuirostris) in fisheries. MSc thesis, Zoology.* Dunedin, University of Otago. 255 pp.

Uhlmann, S. S.; Moller, H. 2000. Fisheries bycatch: Does it threaten the long-term sustainability of Sooty Shearwater (*Puffinus griseus*) harvest by Rakiura Mäori? Proceedings of Conservation of Arctic Flora and Fauna(CAFF) workshop on seabird bycatch in the waters of Arctic countries, Dartmouth, Nova Scotia.

Veit, R. R.; Mc Gowan, J. A.; Ainley, D. G.; Wahls, T. R.; Pyle, P. 1997. Apex marine predator declines ninety percent in association with changing oceanic climate. *Global Change Biology* 3: 23 - 28.

Veit, R. R.; Pyle, P.; McGowan, J. A. 1996. Oceanic warming and long-term change in pelagic bird abundance within the California current system. *Marine Ecology Progress Series* 139: 11 - 18.

Veitch, C. R. 1994. Habitat repair: a necessary prerequisite to translocation of threatened birds. In Serena, M. (Ed.). *Reintroduction Biology of Australian and New Zealand Fauna*, Surrey Beatty and Sons, Chipping Norton, pp. 97-104.

Veitch, C. R.; Bell, B. D. 1990. Eradication of introduced animals from islands of New Zealand. Pp 137-146. In: Towns, D. R.; Daugherty, C. H.; Atkinson, I. A. E. (Eds.). *Ecological restoration of New Zealand islands.* Conservation Sciences Publication No. 2, Department of Conservation, Wellington.

Veitch, C. R.; Clout, M. N. 2002. *Turning the Tide: The Eradication of Invasive Species.* Proceedings of the International Conference on Eradication of Island Invasives, held at the University of Auckland in February 2001. IUCN, Gland. 424 pp.

World Health Organisation. 1995. Anticoagulant Rodenticides. *Environmental Health Criteria* 175: 97 p.

Yearsley, J. M.; Fletcher, D. J. 2002. Equivalence relationships between stage-structured population models. *Mathematical Biosciences* 179: 131-143.

Yearsley, J. M.; Fletcher, D. J.; Hunter, C. (in press). Sensitivity Analysis of Equilibrium Population Size in a Density-Dependent Model for Short-tailed Shearwaters. *Ecological Modelling*: 27.

Appendix A: Calculation of number of tītī killed in the *Command* oil spill and projected rate of replacement.

Pessimistic, median and optimistic scenarios

Our aim in these calculations is to determine the range of number of tītī killed by the *Command* Oil spill and the outer limits in projected rate of replacement of these birds after rat eradication. The outer limits will be extremely wide because in one scenario we have loaded all the pessimistic values of every step in the calculation, and vice versa for the optimistic scenario (Tables A1 and A2). Extreme low or high estimates are most unlikely to occur for all steps in the calculation (a mixture of high and low estimates would be much more probable). The 'median' projection simply uses means or the mid-points between the two extremes. The median is therefore more likely to capture the true rate of replacement of killed *tītī* than the extremes, but we can not categorically rule out that the pessimistic or optimistic scenario could occur.

Estimated Number of tītī killed in the oil spill

Our approach to estimating sooty shearwater mortality uses similar methods to those in the bird injury report for Marbled Murrelet, by comparing the ratio of the number killed to number at risk for the Common Murre to the shearwater, solving for the number killed. The number at risk was determined with at-sea densities observed during aerial surveys at time of spill by the California Dept. of Fish and Game. Aerial surveys estimated densities between 11 and 346 Sooty Shearwater per km^2. The variability in the at-sea density was used to derive the high and low range of estimated killed.

Dead oiled tītī were the second most numerous species recovered in beach surveys (12 of 171 collected, plus 1 unknown shearwater spp.). We provide an estimate of total mortality for this species based on the premises detailed in their document for the estimated mortality of Common Murre and Marbled Murrelet.

Assumptions:

1. Sooty Shearwaters (SOSH) and Common Murre (COMU) have the same probability of becoming oiled and the same amount of oil kills both species.
This is probably valid, since these two species are of similar body size, habits (roost on water, dive to obtain prey) and at-sea distribution (shelf and near-shore waters).

2. SOSH have greater propensity to move out of area after becoming oiled.
This is well support by the fact that a New Zealand banded oiled SOSH was collected at Seaside (Monterey County), 50 km south of the main affected area off the San Mateo Co. coast. Also, SOSH are highly mobile and have flight throughout their time in California (May – Oct), whereas COMU are moulting during the fall and are flightless. Shearwaters are more mobile, and were beginning migration back across Pacific to New Zealand during the time of the spill (Sept, Oct). COMU tend to come to shore when oiled, whereas SOSH may be more likely to stay at sea and sink.

3. Estimate of total mortality to the number at risk of COMU is valid comparative measure for SOSH.
This ratio was used to estimate the total mortality of Marbled Murrelets (although no MAMU were collected dead) resulting from this spill by the Trustee Council and should be valid for the SOSH as well.

Calculation:

The number of SOSH killed relative to the number at risk is proportional to the number COMU killed relative to the number of COMU at-risk.

$$\frac{M_{cm}}{R_{cm}} = \frac{M_{sh}}{R_{sh}}$$

(...... Equation 1).

Where,

M_{cm} = Estimated mortality of COMU (1,490 from Ford 2002)

R_{cm} = Number of COMU at risk (11,193 from Ford 2002)

M_{sh} = Estimated mortality of SOSH

R_{sh} = Number of SOSH at risk (See Below)

Number at-risk (R_{sh}) = Total Area Affected * Average Density (SOSH/km^2)

Total Area Affected was not explicitly detailed in Boyce and Hampton report. Therefore we obtained the area from image analysis of Map 1, Boyce and Hampton (2002). Total Area = (Area A) 560 km^2 + (Area B) 60 km^2 + (Area C) 38 km^2

= 658 km^2

Average Density was calculated with data from aerial surveys provided in Table 2 of Boyce and Hampton (2002).

Ave. Density (SOSH/km^2) = {346.25(Sept. 29); 280.27 (Sep. 30); 73.00 (Oct. 1); 11.72 (Oct 2)} = 177.81, SD =160.6

We used plus/minus one standard deviation (SD) to generate low and high ranges of mortality estimate. (e.g. low is 177.81 + 160.6 = 338 SOSH/ km^2; high is 177.81 – 160.6 = 17 SOSH/ km^2).

Therefore, the number at-risk (R_{SH}) = 658 km^2 * 177.81 SOSH/ km^2 = 117,124 SOSH (Low/High Range: 11,186 – 222,404 SOSH[71]).

Following this, we solved for Total Mortality (M_{SH}) in equation 1, with low and high estimates, giving: 1,490/ 11,193 = M_{SH} / 117,124, = 15,591 Shearwaters killed (Low/High estimates: 1,489 – 29,606)

---

[71] This is same order of magnitude of densities observed during boat surveys conducted during the spill, including a flocks of 6,000+ at Pillar Pt. 29 Sep 98 (Area B: 6,000/60 = 100 birds/km), and "several hundred" near Pescadero 2 Oct 98 (Area C: 500/38 = 13 birds/km).

Conclusion: Number of tītī killed.

Most probable estimates are for 15,591 (range 1,489 to 29,606) tītī having been killed. We believe this is probably within the order of magnitude of the numbers directly affected by the *Command* spill. Many more birds could have potentially been affected by sub-lethal ingestion, thus having affects on reproduction and survival; these effects were not measured.

Calculation lost production because of the Command spill

A 'Leslie Matrix' model has been generated on an Excel™ spreadsheet to calculate the number of tītī lost from the population in successive years after the spill. The simulation used estimates of annual survival for chicks, juveniles and prebreeders and proportion of adults skipping breeding as for the 'Average breeder' model[72] for short-tailed shearwater, a sibling species with very similar demography, ecology and behaviour. Determination of the age at first reproduction of tītī is not yet complete, but a few of our banded birds have begun at 4 years and more at 5. We expect the mean age at first reproduction to be slightly more[73] than the 6-7 years seen for short-tailed shearwater in Australia[74]. Accordingly our simulation has assumed that all tītī first breed at age 7.

We assumed that all ages of tītī were equally likely to have been killed in the oil spill. Initial stable age structure was therefore first estimated by a vertical life-table calculation using the parameters in Table 1 of Hunter *et al.* (2000).

The number of missing tītī was then determined by projecting the Leslie Matrix forward from 1998 (the year of the spill) for 50 years, starting with our pessimistic, median and optimistic estimates of the number killed (29606, 15591 and 1489 respectively).

---

[72] See Table 2 in Hunter *et al.* (2000).
[73] Sooty shearwaters are slightly bigger than short-tailed shearwaters and the bigger the bird, the longer reproduction is delayed (Croxall 1984, Croxall & Gaston 1988).
[74] Serventy & Curry (1984).

The number of tītī predicted to be missing from the population because of the spill changes linearly for the first 6 years because of expected natural wastage of the juveniles and adults and the lost production of chicks from killed breeders. By year 7 after the spill (2005), the number of missing tītī compounds because of the absence of prebreeders reaching breeding age.

By the earliest feasible time of the rat eradication (2004) initial injury levels are projected to have become 2417, 20820, 34931 for optimistic, median and pessimistic scenarios respectively because of lost production of the killed cohort.

Calculation of rate of replacement of tītī following rat eradication

There are no extensive surveys of the area of Taukihepa covered by 'manu' (breeding ground), but the *Kia Mau Te Tītī Mo Ake Tōnu Atu* research team's visits to part of the island suggest between 35% (pessimistic) and 55% (optimistic) of the island has breeding colonies. Our calculations of the area of manu protected by rat eradication (Table A1) assume that all of Pukeweka, Rerewhakaupoko and Mokonui are covered in manu (breeding ground).

We estimated the number of chicks per m^2 of manu based on transect counts of entrance holes and burrow occupancy estimated by burrowscoping just before chicks fledged at Pukeweka and on the southern end of Taukihepa in the 1998/99 – 2001/02 seasons[75]. Burrowscoping probably underestimate occupancy[76] so our calculation of restoration rate is conservative. Our pessimistic scenario uses the lower 95% confidence interval for chicks per m^2, and the optimistic scenario uses the upper 95% confidence interval. We have assumed that the density of chicks on the northern end of Taukihepa, Rerewhakaupoko and Mokonui is about the same as on our transects elsewhere.

[75] Newman *et al.* (2002a, c, e); Scott *et al.* (2002 a, d).
[76] Hamilton *et al.* (1997, 1998).

Table A1. Calculation of the number of extra tītī fledglings produced annually immediately following eradication of rats from the four islands.

	Pessimistic Scenario	Median scenario	Optimistic scenario
Assumed % of Taukihepa covered by manu	35%	45%	55%
Area of manu from which rats will be eradicated (Ha)	455.1	548.0	640.9
Chick production per m^2	0.149	0.212	0.274
Current total chick production from manu from which rats will be eradicated	680,292	1,159,182	1,753,351
Proportion harvested	0.20	0.15	0.10
% predation by rats	1%	5%	10%
Extra fledglings each year for first 6 years after rat eradication	5497	51,858	175,335

We do not have exact data for harvest off-take rates for these islands, because we do not have accurate information on the proportion of breeding ground remaining unharvested. We have set 10 – 20% harvest rates as probable overestimates (Table A1) so that the calculations can be interpreted as being overly cautious about the expected rate of repair of the injury from the oil spill.

Calculation of the rate of replacement of tītī killed by the *Command* Oil spill is dependent on knowing what proportion of the eggs and early stage chicks are currently killed by rats. While we know that some losses do occur to rats, there has been no systematic study of predation rates of tītī by black rats or kiore. Assuming that the very high rates of egg and chick loss reported for Norway rat predation also apply to black rats is clearly inappropriate – otherwise the birders would have noticed a huge drop in harvest rate when rats arrived on Taukihepa, Pukeweka and Rerewhakaupoko. However, chick harvest rate is related to chick density in a curvilinear way[77] because once moderate densities of chicks are present the main determinant of harvest rate is the chick 'handling time' rather than chick encounter rate. The hunter is therefore 'saturated' and even quite major changes in density of chicks have little noticeable effect on harvest rate. Accordingly there may have been considerable impacts on tītī productivity without immediate impact on harvest rates.

We consider that it is very unlikely that 20% of the chicks are killed by rats in most years (predation during extreme peaks in rat abundance during the irruptions on Taukihepa and Kaihuka are exceptions) but we infer that up to 10% could be taken in normal years as follows. Rat density in the order of 10 per hectare is expected on offshore islands[78] and rats are regularly seen on Taukihepa. Every hectare of manu has approximately 2100 chicks, so every rat would have about 210 chicks available to it. Chicks are guarded for the first week after hatching (late January) until they can thermoregulate without being sat on by the parents. By mid March the chicks are big and capable of delivering a sharp bite. This leaves at least 6 weeks where the parents are usually not present to guard the chick and when the chick will be relatively defenceless. The chicks are therefore vulnerable for at least 6 * 7 = 42 days. A rat would only have to kill 1 chick every 2 days, a very plausible predation rate[79], to destroy 10% of the chicks.

It is therefore entirely plausible that between 1% and 10% of the eggs and/or chicks are killed by rats. We used 10% as the 'optimistic' scenario because the higher the assumed predation rate, the faster the mitigation of the oil spill injury if rats are eradicated. Median and pessimistic scenarios were set at 5% and 1% respectively (Table A1).

---

77 Lyver (2000), Kitson (in press).
78 Daniel (1978), Moller & Craig (1987).
79 Often rats only consume a small part of a kill.

Multiplying assumptions for each scenario about area of manu, chick density, proportion of chicks not harvested and assumed current probabilities of escaping rat predation, leads to prediction of the extra productivity possible if rats were eradicated. We predict that an extra 5497, 51858 and 175335 fledglings will be produced in the season immediately following rat eradication for pessimistic, median and optimistic scenarios respectively (Table A1).

These annual additions to the tītī population were then incorporated into Leslie matrix model using the parameters in Table A2 to simulate potential rates of recovery of tītī in the years following rat eradication. Pessimistic recovery rates are simulated using (i) the minimum number of extra fledglings following rat eradication, (ii) minimum juvenile, pre-breeder and adult survival, (iii) minimum breeding success and (iv) minimum proportion of adults not skipping breeding in a given year (Table A2). Optimistic recovery rates used maximum productivity and survival parameters. All scenarios assumed first reproduction at 7 years.

Resulting rates of recovery in relation to the size of the injury from the oil spill are presented in Table 1 and Fig. 2 in the main body of this report (Pp 20 and 21).

Table A2. Parameters for Leslie Matrix models to calculate the rate of replacement of tītī following eradication of rats from the four islands. The parameters are taken from Table 1 of Hunter *et al.* (2000) except that all tītī are assumed to start breeding at age 7.

	Pessimistic Scenario	**Median scenario**	**Optimistic scenario**
Juvenile survival	0.534	0.583	0.63
1st year Pre-breeder survival	0.838	0.867	0.891
2nd year Pre-breeder survival	0.902	0.923	0.939
3rd year Pre-breeder survival	0.919	0.938	0.951
4th – 6th year Pre-breeder survival & Adult survival	0.901	0.912	0.923
Proportion of fledglings reaching adulthood (7 yrs)	0.271	0.332	0.394
Age at first reproduction (years)	7	7	7
Proportion of adults skipping breeding in any year	23%	31%	33%
Breeding success	59%	61%	64%

Appendix C: Costs of eradication of rats from Taukihepa, Pukeweka, Rerewhakaupoko and Mokonui islands.

Calculation of cost of rat eradication

Area requiring coverage by poisons:

Taukihepa - 939ha
Solomon (Rerewhakaupoko) - 30 ha
Pukeweka - 3ha
Mokonui – 86 ha

This is a total area of 1058 ha, and gives a working area to be covered of approximately 1400ha including double runs on cliffs etc.

Bait cost (21 tonne) includes 20% contingency, transport and storage, this is calculated at 2 drops by helicopter, 1 of 8 kg/ha and 1 at 4kg/ha (this is standard to make sure there are no gaps and in case of bad weather).
……NZ$128,000[80]

Bait deployment costs

Helicopter hire for bait drops	NZ$ 98,000[81]
Boat to transport bait	NZ $ 15,000
Helicopter ferrying bait	NZ$ 23,000
Boat and Helicopter ferrying people[82]	NZ$ 32,000
Boat and helicopter for reconnecting water systems after drop	NZ$ 20,000[83]
Consents, forecasts, bait testing, safety gear etc.	NZ$ 12,000[84]
Post drop monitoring	NZ$ 20,000
Total eradication cost:	NZ $ 348,000

[80] All the costs are listed in this Appendix are in New Zealand Dollars unless otherwise stated. At the time of writing this proposal the local currency exchange rate was 1 NZ Dollar = 0.517 US$.
[81] This is a minimum estimate that assumes that Peter Garden is available. Otherwise we must add another $15000 to bring in another suitable pilot.
[82] A dedicated team is needed to put bait around all the houses on the islands on the day of the drop.
[83] This is based on taking down a limited number of people on a catameran and ferrying them to the sites to do the work – if each whānau wanted someone to go down this would increase substantially.

This calculation does not include "help in kind" to the project from the Department of Conservation from supervising the application of poisons. We estimate this contribution to be around 125 people-days (assuming lengthy preparations for Environment Court hearings are avoided). At a standard DoC charge out rate of NZ$52 per hour, this equates to US$101,000 in-kind assistance to the Rakiura Tītī Islands Restoration project.

---

[84] This will increase if the proposal must go to the New Zealand Environment Court.

Cost of Rakiura Mäori scientist/manager for monitoring and quarantine programme

An annual salary of NZ $ 35,000 is required and ca NZ$ 15,000 in expenses (transport, bait stations and poison baits) for years when both monitoring and quarantine tasks are being completed (2003-2006; 2012 & 2013). More than one Rakiura Mäori community member will be employed for part of the year so that support peaks at the time of fledging. $10,000 of this allocation will be dedicated to quarantine issues every year throughout the programme.

University of Otago science studies to monitor and report outcomes and predict long-term restoration.

Around NZ$ 11,000 is needed in each of the first two years to establish new benchmark plots on impact islands to assess the effect of rat eradication. This involves a team of 4 people monitoring working in the field for 3-4 weeks each year. An intensive study of rat predation for 4 years (two before impact, two after) will require NZ$ 15,000 per year and an additional NZ$ 20,000 in 2006 to synthesise, model and report the predicted rate of recovery of the oils spill injury from all these preliminary studies. NZ$ 20,000 has been allocated for the last year of the RTRP (2013) to re-survey the impact and control plots and check whether model predictions have been realised and publish the outcomes in a peer reviewed journal.

Collaboration between New Zealand and USA scientists and educationalist

We have scheduled visits of Hannah Nevins and Josh Adams to New Zealand (visits in 2003, 2004, 2005, 2012 and 2013 (@ NZ$ 11,000 per visit) to participate in fieldwork, study design, synthesis and publication. Similar visits by Dr Dick Veit are scheduled for 2004 and 2006 (@ NZ$ 5,000 each). Reciprocal visits by Drs Moller or Newman from the tītī research team to USA are scheduled for 2005 and 2013 (budgeted @ NZ$ 5,000 each).

Production of Tītī Times, Films and Educational packages for quarantine and outreach

A special issue of *Tītī Times* on quarantine issues will be prepared and distributed in 2004 (cost NZ$ 4,500) and a fifth of issues in all other years (@ NZ$ 1800 per year) to build awareness and dedication to quarantine efforts.

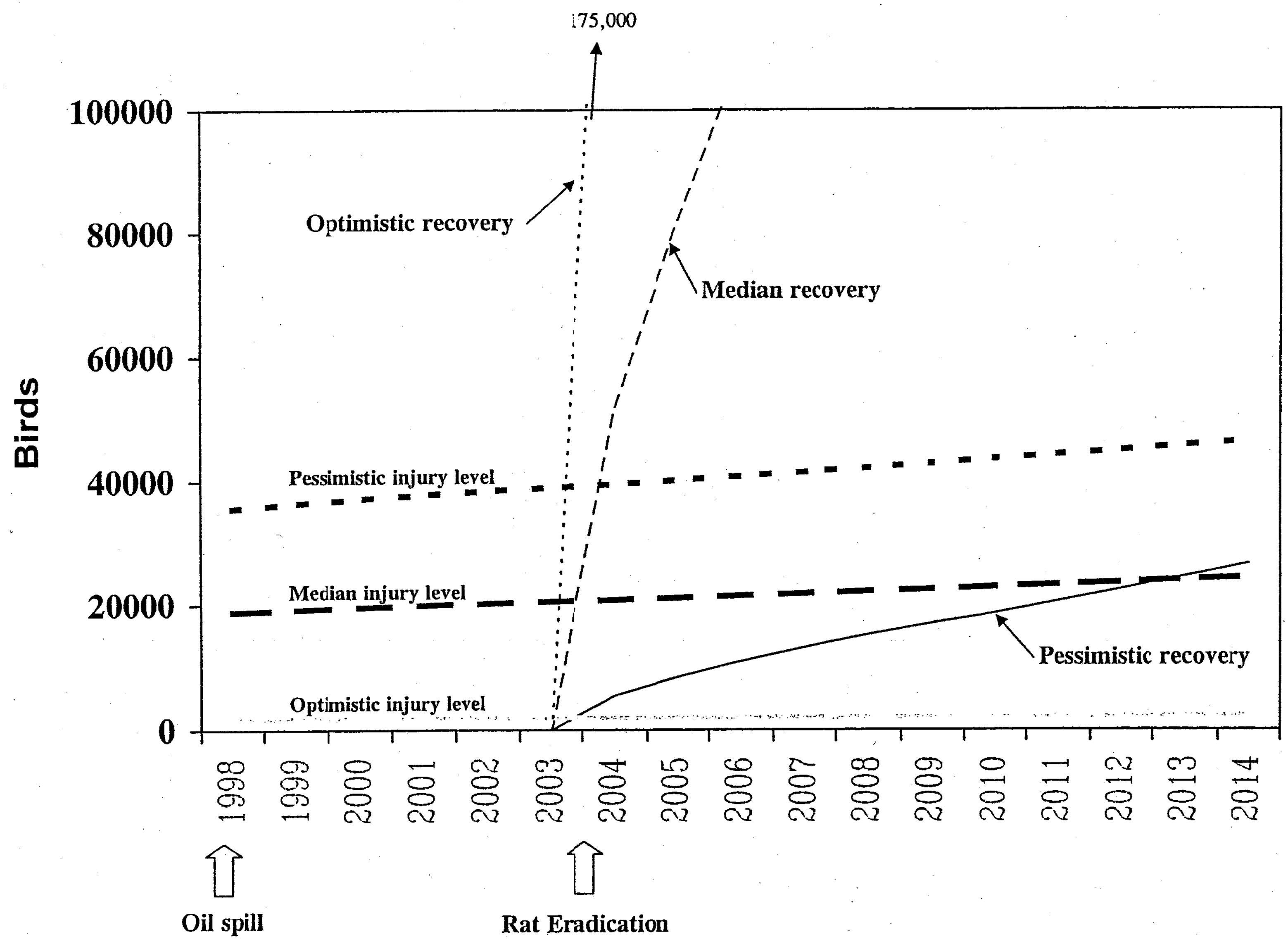
A provisional budget for NZ$ 22,000 has been allocated to preparing the natural History film about the restoration project. This will be used for both general public outreach and educational packages for schools and quarantine education and workshops, so half of its cost was allocated to the quarantine budget and half to the educational outreach in Table 2.

Preparation of educational material, websites etc, by *Oikonos* is costed as USA$ 5,000 in each of 2004, 2005 and 2013.

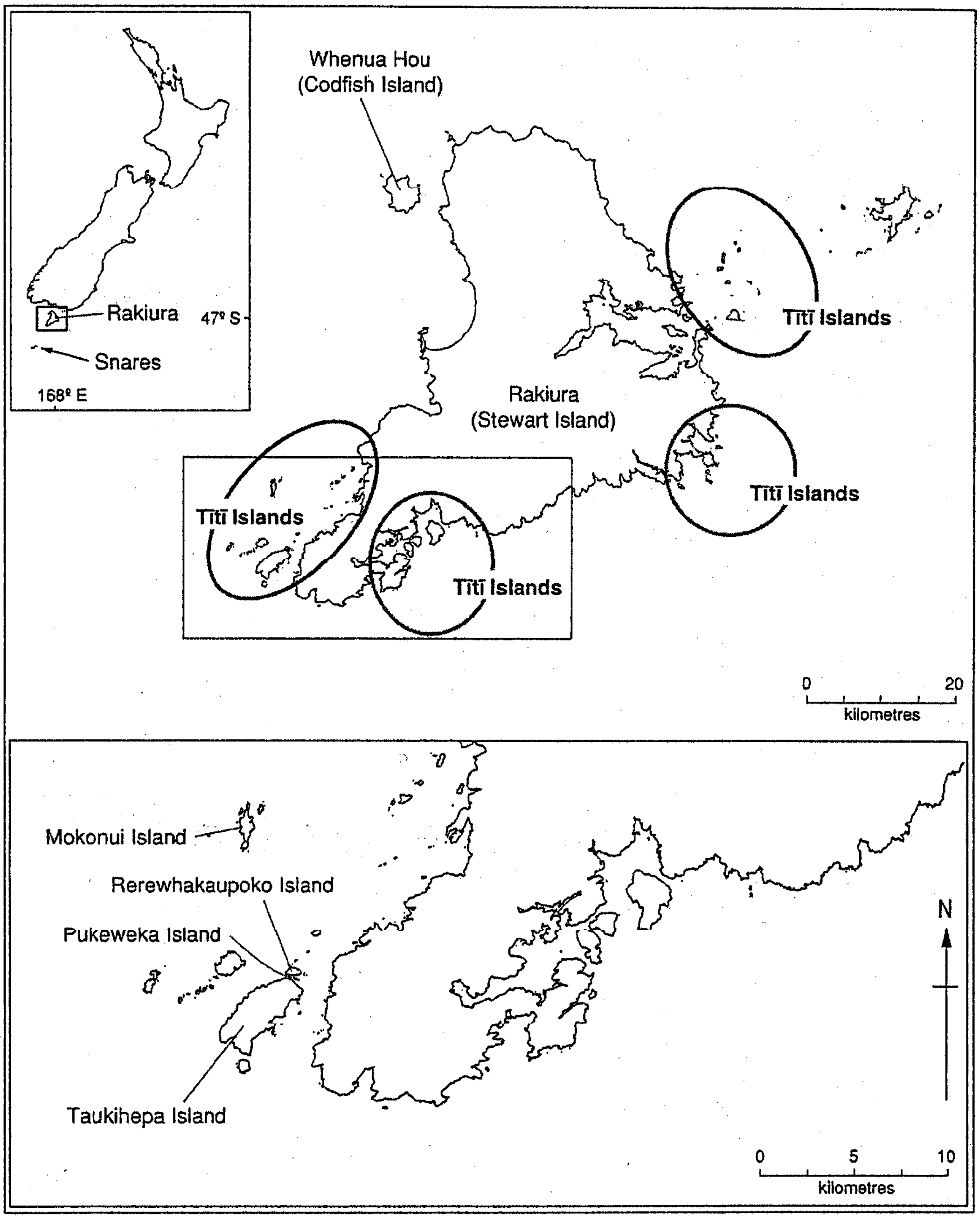
Support by the kaitiaki

Rakiura Māori kaitiaki will help in eradication operation, planning, resource consent application, negotiation and monitoring of the overall project, reporting and filmmaking. NZ$ 17,500 has been allocated per year for the first 3 years (2003 – 2005) for this role, followed by NZ$ 9,000 in the last year (2013) for final synthesis, reporting and closure issues. At least one visit to the *Command* Trustee Council in California will be requested and funded out of this allocation.

Appendix D: Letter of support from the New Zealand Department of Conservation



175,000
Birds
100000
80000
60000
40000
20000
0
Optimistic recovery
Median recovery
Pessimistic injury level
Median injury level
Optimistic injury level
Pessimistic recovery
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Oil spill
Rat Eradication



Whenua Hou
(Codfish Island)
Rakiura
47° S
Snares
168° E
Tītī Islands
Tītī Islands
Rakiura
(Stewart Island)
Tītī Islands
Tītī Islands
0
20
kilometres
Mokonui Island
Rerewhakaupoko Island
Pukeweka Island
Taukihepa Island
N
0
5
10
kilometres

Kia Mau Te Tītī Mo Ake Tōnu Atu:
Goals, design and methods

A Research Planning Report by the University of Otāgo Tītī research team
for the Rakiura Tītī Islands Committee, Muttonbirders,
the Department of Conservation and research sponsors.

By

H. Moller, J. de Cruz, D. Fletcher, K. Garrett, C. Hunter, C. J. Jones,
J. Kitson, P. Lyver, J. Newman, B. Russell, P. Scofield, and D. Scott.

Te Tari o Whakāro Kararehe (Department of Zoology)
Te Whare Wānanga o Otāgo (University of Otāgo)
P.O. Box 56
Dunedin

University of Otāgo Wildlife Management Report Number 117

October 1999

ABSTRACT

The harvest of tītī (*Puffinus griseus*; "muttonbirds") on islands adjacent to Rakiura (Stewart Island) is one of the few remaining wildlife harvests managed entirely by Māori. The harvest is of great social and cultural importance to Rakiura Tangatawhenua and to Māori in general. The muttonbirders have requested this study to examine the sustainability of the harvest to ensure that the birds remain plentiful for their mokopuna (grandchildren). It will test and refine population monitoring methods; measure whether current tītī harvests are sustainable; estimate maximum sustainable yield; determine what limits the tītī harvest levels so impacts of any future changes to technologies or harvest practices can be predicted; evaluate potential impacts of climate change, fisheries bycatch and pollutants on tītī populations; and record and compare the understanding of tītī ecology, harvest impacts and management practices generated from Mātauranga and kaitiakitanga with that from ecological science. Under this program adults and chicks will be banded on both harvested and unharvested islands, the harvest observed, and survival of chicks and adults monitored. Harvest impacts will be estimated by computer simulation models. Trends in population on unharvested areas will be compared with trends on harvested sites to test the model's predictions. Tītī density on harvested and unharvested colonies will be compared for further rapid check of large-scale harvest impacts. Traditional Environmental Knowledge (Mātauranga) will be recorded using oral histories of experienced muttonbirders and questionnaires. Kaitiakitanga and Eurocentric conservation philosophies will be compared using records of discussions at hui of tītī harvesters, environmental managers and conservation stakeholders. The research is conducted by the University of Otāgo, but is directed by the Rakiura Tītī Islands Committee. Approximate estimates of sustainable yields will be formulated by 2006, and then must be checked and refined by monitoring, adaptive management and ongoing research.

Mihi

Ko Hananui te Mauka

Ko Rakiura te Whenua

Ko Te Ara a Kewa te Moana

Ko Kai Tahu te iwi

Tihei Mauriora

Rau rakatira ma, tēnā koutou, tēnā koutou, tēnā koutou.

Ko taku inoi mo ka uri o ka motu o ka tītī.

Whakahokia mai ki roto i ka hinekaro,

Te kaha ki te whawhai.

Kia tu takata ai tatou katoa.

Kua hono te iwi o Rakiura me te Whare Wanaka o Otakou,

Ki te kimi, ki te tiaki i ka taoka me ka mea pai o ka motu o te tītī.

Kia mau te tītī mo ake tonu atu.

He taoka tuku iho hoki na o tatou tupuna.

Ahakoa kei te noho tatou i roto i te ao hurihuri,

Kei te mau tatou ki tenei mahi whakahirahira.

Kahore e nui ake aku kupu,

He mihi tonu ki a tatou.

Apiti hono tatai hono,

Te huka mate ki te huka mate.

Apiti hono tatai hono,

Te huka ora ki te huka ora.

No reira, tēnā koutou, tēnā koutou, tēnā koutou katoa.

Paddy Gilroy.

CONTENTS

INTRODUCTION: THE NEED FOR THIS RESEARCH

The importance of the tītī harvest and a bicultural approach:
Tītī (*Puffinus griseus*, otherwise known as Sooty Shearwaters, *tītī* [1] or muttonbirds) are *taoka* of *Rakiura* Māori. Tītī return from the northern hemisphere from late September to early November to breed on offshore islands and a few remaining mainland New Zealand colonies (Warham *et al.* 1982, Hamilton *et al.* 1997b). Their annual cycle[2] is depicted in Fig. 1. For centuries they have been harvested by *Waitaha*, *Ngāti Māmoe*, and *Ngāi Tahu*, mainly from the islands around Rakiura (Wilson 1979; Dacker 1990). Large-scale harvest may be a protohistoric phenomenon (Anderson 1997, 1998). The chicks are a food source that is preserved and then used year-round. The tītī harvest continues to be economically important for some Rakiura Māori (Waitangi Tribunal 1991), and has a special cultural significance as one of the few remaining large-scale harvests of native wildlife remaining largely within the control of Māori. *Tangatawhenua* are anxious that tītī remain numerous for their *mokopuna* to harvest.

In 1994 Rakiura Māori invited a team from the University of Otāgo to apply ecological science methods to determine whether the current tītī harvest levels are sustainable (Moller 1996). The *kaitiaki* for the study called it the *Kia Mau Te Tītī Mo Ake Tōnu Atu* (Keep the Tītī Forever) Research Program. In accordance with the principles of *whānaungatanga*, the decision to initiate the research and approval of the research methods have been reached by consensus following lengthy discussion amongst the Rakiura tītī harvesters and the University research team. The Rakiura Tītī Islands Committee are the kaitiaki for the study and liase and direct the research team on behalf of the wider harvesting community. The committee periodically seek direction about the study from the annual "Permit Day" gathering. A "cultural safety contract" guides the working partnership between the University of Otāgo and Rakiura Māori (Taiepa *et al.* 1997; Moller 1998a).

The result is a community-based project and working partnership between Rakiura Māori and the University of Otāgo Zoology and Statistics Department team. We do not claim that this project is a model in the ideal sense of the word, but it represents a sincere attempt by Rakiura Māori and the University of Otāgo to smooth out a system for working together in a bicultural way, and for scientists and kaitiaki to share and compare their knowledge and approaches to understand the natural world surrounding tītī and their harvest. Similar bicultural partnerships could assist many natural resource management issues in New Zealand.

A large-scale harvest of short-tailed shearwaters in Tasmania has received detailed study (Skira & Wapstra 1980, Skira *et al.* 1985, Skira 1993). The harvest is strictly regulated below the estimated maximum sustainable limit (Skira and Wapstra 1980, Skira *et al.* 1985). Over-harvesting by amateurs has probably caused localised declines in bird abundance in some small colonies, mainly to the south and west of Tasmania (Norman 1985). More restrictive bag-limits and closure of some of these colonies were imposed in 1988 and 1990 (Tasmania Parks & Wildlife Service, 1997). Few problems are experienced with the commercial harvesters who take many fewer than the estimated maximum sustainable take. Harvesting of sooty shearwaters in New Zealand has received no scientific study until this project, and there are no published scientific measurements of the overall size of the harvest, or its impact on tītī numbers.

---

[1] Māori words are given in italics at their first mention and are defined in Appendix 6. We have followed the Kai Tahu dialectal preference for using 'k' for 'ng'.

[2] Breeding seasons will be referred to by the year of spring/summer egg-laying followed by the year of chick maturation (e.g. 1998/99 refers to any part of the breeding season starting from October 1998 and ending in May 1999). A harvest of chicks begins on 1 April and ends by 31 May, so a single year is given when referring to a harvesting season.

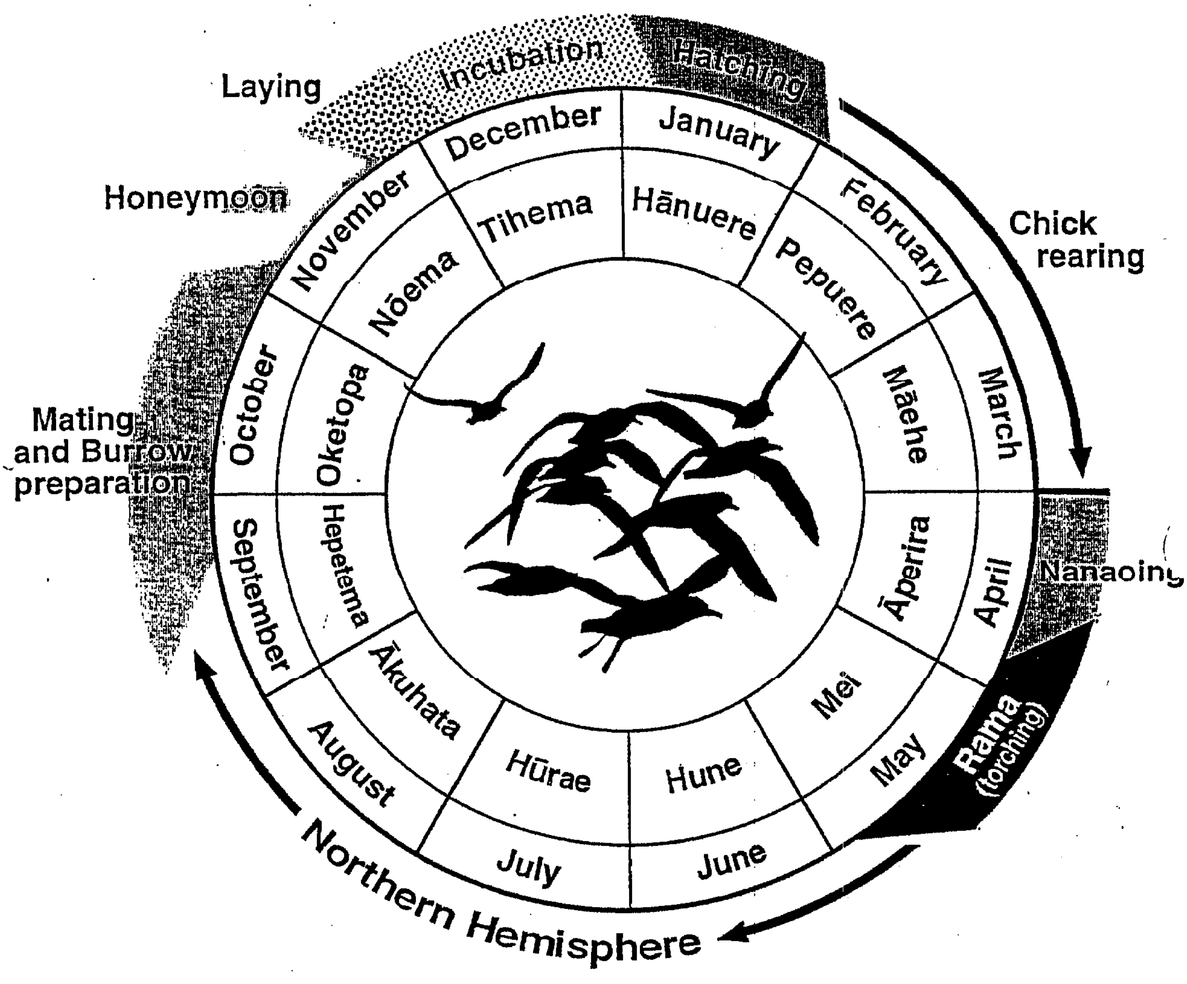


Fig. 1: The annual cycle of the tītī (*Puffinus griseus*) and the Rakiura Māori chick harvest. See Warham et al. (1982) for detailed dates of breeding cycle.

The need for case studies of Kaitiakitanga in action

Although the primary aim of this project is to safeguard the long-term viability of the harvest for Rakiura Māori, it also informs more general issues of bicultural approaches to natural resource management in New Zealand. The role of *kaitiakitanga* in resource decision making is under intense scrutiny following its inclusion in the Resource Management Act, but the dilemma is that it is poorly understood by many people and managers (Ballantyne 1994, Taiepa *et al.* 1997). This is of particular importance for circumstances where differences have been expressed between Māori and *Pākehā* approaches to conservation management (eg. Dickison 1994, Hodges 1994, Te Puni Kōkiri 1994, Smith 1994, Roberts *et al.* 1995). Conflict between Māori and non-Māori conservation philosophy has been highlighted by recent initiatives to reinstate Māori Customary Use of native wildlife (Kirikiri & Nugent 1995, Moller 1996, New Zealand Conservation Authority 1997). The utility of Traditional Environmental Knowledge (TEK) compared to science for environmental stewardship is under much debate overseas as well as in New Zealand (Diamond 1992, Johnson 1992, Berkes 1993, IUCN 1997). Our study aims to inform these debates with a detailed case study of kaitiakitanga and TEK in action within *Aotearoa*.

Vehement denial by many Pakeha that Māori can adequately manage the New Zealand environment was seen in their submissions to the Southland Conservation Board on the proposed return of the ownership of the Crown Tītī Islands to Ngāi Tahu ownership (Southland Conservation Board 1994) and their submissions to the New Zealand Conservation Board on Customary Use of Wildlife (NZCA 1997). These submissions have challenged whether adequate TEK (*Mātauranga Māori*) still exists amongst Māori; whether it can ever be sufficient to ensure sustainable use; and whether it can guide within new ecological conditions prevailing in New Zealand. The impact of new technologies may have made current tītī harvest rates unsustainable, especially when the resource itself has potentially come under increasing pressure from new threats such as introduced predators, fishing impacts on food, bycatch in fishers' nets and lines, and climate change. If there is no confidence in Mātauranga Māori and kaitiakitanga for monitoring trends in the harvested resource (and if necessary for regulating the harvest), then the impacts of the new harvest technologies are assumed to make the traditional practice unsustainable. Rakiura Māori on the other hand assert the value and utility of their Mātauranga in safely guiding a sustainable tītī harvest (see appendix in Taiepa *et al.* 1997). This is a local example of strident but acrimonious debates in several countries as the Indigenous People's have reasserted their traditional power and responsibilities as wildlife managers (Pye-Smith & Feyerabend 1994, Borrini-Feyerabend 1996, Posey 1996). The international conservation movement has recently recognised a need to empower local communities to make their own decisions about environmental problems (Borrini-Feyerabend 1996). This study aims to assist co-management of the tītī harvests by Rakiura Māori.

The ecological importance of titi

Tītī are probably New Zealand's most abundant seabird (Richdale 1944, Warham & Wilson 1982). Very abundant species have received less study by conservation biologists in recent decades because most of their limited resources are dedicated to understanding how to halt declines or rare or endangered species. Māori with an interest in customary use of native plants and animals have traditionally benefited little from ecological science (Moller 1996). Research on traditional harvest species is rarely dedicated to study of the key parameters needed to facilitate harvest and ensure any harvest is sustainable. Nevertheless, the study of an abundant species like tītī has several potential spin-offs for management of rarer species and for predicting large-scale changes to nature reserves with rarer species. The most abundant species are usually the most ecologically important. Tītī are probably the "keystone" or "critical species" (Paine 1966, 1994) on the 36 Tītī Islands around Rakiura (Appendix 1; Fig. 2), and on The Snares. Their burrowing and guano deposition affect soil formation, aeration and nutrients, and regeneration and vegetation succession (Campbell 1967, Towns *et al.* 1990, Furness 1991).

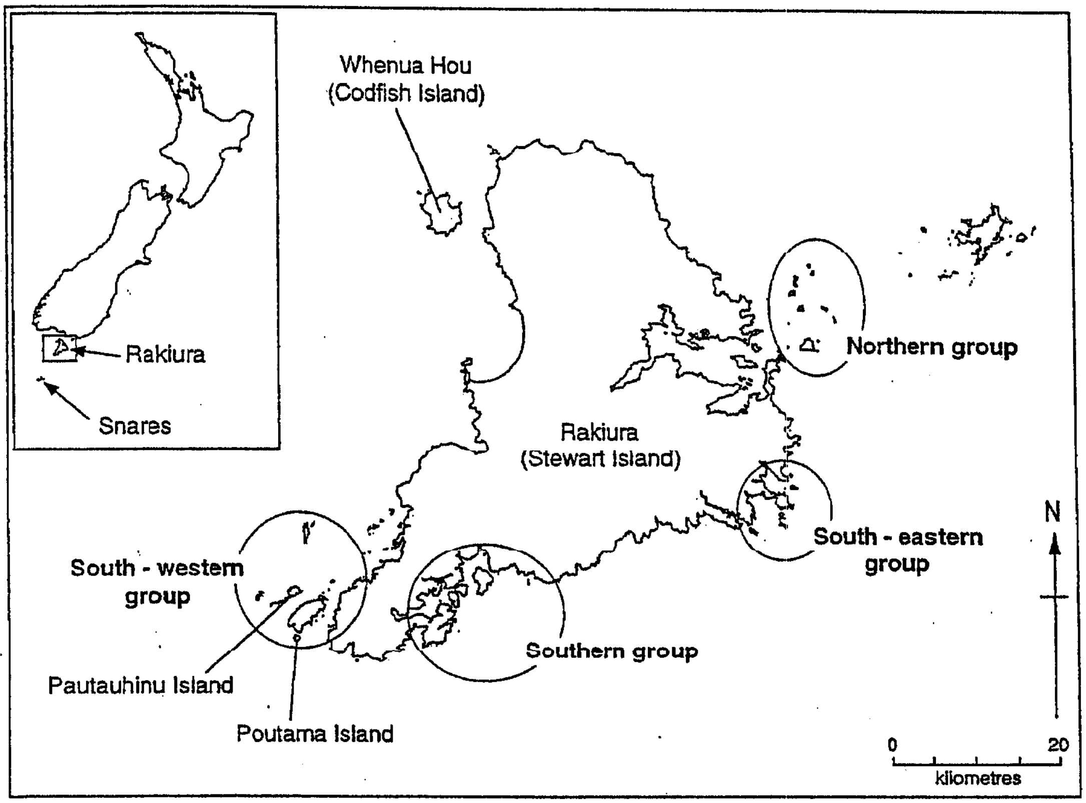


Fig. 2. Location of the main Tītī Islands from which birds are harvested. Each island is listed in Appendix 1.

Other benefits from this study

Techniques developed for the study of tītī may assist other threatened species work. For example, an electronic system developed by our research team to study provisioning and emergence behaviour of tītī is now under consideration for use in the Taiko (*Pterodroma magentae*) recovery program (C. J. Robertson, pers. comm.). The very abundance of the tītī means that more risks can be taken in developing and testing the safety of research techniques (e.g., the development of harnesses for attaching radio-transmitters for tracking by satellites). Statistical needs are more easily met by working on an abundant bird. Study of abundant and wide-ranging seabirds can help monitor the well being of the marine environment (Furness & Camphuysen 1997) and levels of pollutants (Muirhead & Furness 1988, Thompson *et al.* 1990, Lock *et al.* 1992, Cruz *et al.*, in prep. b). Finally, the regular harvest of thousands of chicks for food provides an opportunity to sample tissues and diet in a way that would be more difficult to justify for other species. It is important to take advantage of the harvest to further understanding of the biology and ecology of procellariiformes that eventually will assist managers to conserve rarer species and whole ecological communities on the island nature reserves.

The need for this report
The project's aims have been described by Moller (1996) and Taiepa *et al.* (1997). However, there is a need to detail the design of the ecological science program for the kaitiaki, fellow researchers, sponsors, funders and collaborative management agencies. The Department of Conservation has a crucial role to play along side the kaitiaki for this research which must meet both the Rakiura Tītī Islands Committee's and DoC's needs before it is permitted. DoC have a key statutory responsibility to administer the Wildlife Act and Reserves Act. DoC needs a description of the overall project design against which it can evaluate annual applications for permits to visit islands, band birds, collect diet samples etc. The kaitiaki for the study (the Rakiura Tītī Islands Committee) change from time to time so there is a need for new members of the committee to have a document describing the detail of the science methods and why they have been designed in that way. Similarly, parts of the research effort are supported by several relatively short-term student projects, so there is a need for an overall description of the approach within which they will focus on particular aspects. Finally, the cultural safety contract guiding this research stipulates that Rakiura Māori can submit the research data to an independent peer review panel for a second opinion on the final predictions of the sustainability of the current harvest. This demands that a detailed research rationale, design and methods are spelled out, and data must be annotated so that a reviewing research team can understand what has been done and why.

This report provides the detailed description of the science design needed by all the above collaborators, agencies and potential peer reviewers. Another version of this report, written in lay terms, is in preparation for use by all muttonbirders.

The need for flexibility
A compromise must be struck between planning likely research priorities at the outset and remaining sufficiently flexible to respond to changing priorities as the research unfolds and information is gained on new threats. We hope that the main structure and intensity of our study will remain substantively as outlined in this report. Possible looming research themes during the last half of the 10-year tītī research project are outlined in Appendix 2.

SCIENTIFIC OBJECTIVES

Rakiura Māori requested our research team to:

1 measure the current level of tītī harvest and assess whether it is sustainable in the long-term.

2 provide guidance on where and by how much harvest must be increased or decreased in order to ensure sustainability of the harvest and to maximise the harvest opportunity.

3 provide base-line measures of tītī abundance and establish monitoring methods (so that any future changes in tītī numbers can be detected).

4 determine what sets the limit of the past and present tītī harvest levels so that the impact of any future technologies or changed practices can be predicted.

5 determine the diet of tītī so that future research on food species might identify threats to the well being of tītī.

6 begin research on the impacts other than harvest on tītī populations, including potential impacts of climate change, food failure, fisheries bycatch, introduced predators and pollution.

7 record and compare the understandings of tītī ecology, harvest impacts and management generated from traditional Mātauranga Māori and kaitiakitanga with that from ecological science and wildlife management.

Some of these objectives are recast in a manner required for the Foundation for Research Science and Technology (FRST). Inevitably the funds available from FRST could not meet all of the kaitiaki's needs, so their specific contracted objectives cover the most important subset of the research aims listed above.

SOCIAL & CULTURAL OBJECTIVES

The models for science involvement alongside traditional Māori wildlife management are only now being developed so there will be a need for trust and perhaps adjustment of procedures as the endeavour unfolds. Accordingly, both parties agreed to work towards the following social and cultural outcomes:

(a) Ensure that ecological science supports rather than obstructs Rakiura Māori management of wildlife.

(b) To ensure that Rakiura Māori remain in control of the harvest and that they retain control over the release of information generated from the research program.

(c) Maximise Māori involvement in the research program, initially in setting research directions, doing fieldwork, interpreting and communicating results, but eventually in undertaking the research itself. Rakiura Māori will be employed in fieldwork and the involvement of tītī harvesters in the research effort will be facilitated as much as possible. Monitoring methods will first have to be designed, tested and refined, but thereafter could be maintained by Rakiura Māori.

(d) Provide results and lessons from which the Rakiura Māori are able to consider the possible re-establishment of other customary uses of wildlife and to enable them to confidently support the efforts of other Māori to do the same.

(e) Honour the Treaty of Waitangi and *tikanga Māori* in the way this research program is planned, executed and communicated to all those concerned.

Although the kaitiaki are to manage public statements about the research results, a cultural safety contract ensures that the scientific findings from the research can be published in the scientific literature without erasure, or omissions, no matter what the research concludes about the sustainability of the tītī harvest. In this way the scientific ethics of the research team are safeguarded and the public is assured of learning about the outcomes.

OVERALL PROJECT DESIGN

Three complementary approaches that check each other
A three-pronged approach for estimating the sustainability of harvests has been mounted: (i) population trends will be estimated and compared for harvested and unharvested sites; (ii) the abundance of tītī at both harvested and unharvested sites will be compared; and (iii) we will build mathematical simulation models based on measures of reproduction and immigration and mortality, emigration from the population.

These three approaches will combine to:

- estimate the effects of harvest as currently practised on tītī population abundance;
- estimate the effects of harvest as currently practised on population densities;
- predict changes to population density and harvest rates if current harvest methods, times, and practices change; and
- estimate the potential effects of climate change and fishery bycatch on bird numbers and harvest opportunity.

The first approach (the "monitoring method") demands that we test and develop robust and repeatable survey methods. Its strength is that it represents hard information on what has actually happened (leaving few unknowns provided that robust survey methods have been developed and applied). The second approach assumes that harvest is the main reason for any observed differences in current density between harvested and unharvested colonies. The fundamental weakness of these first two approaches is that they can not predict what will happen if ecological conditions, harvesting or management changes in future. They look backward, not forward. The third ("demographic prediction") approach predicts population trends if management changes, but inevitably will have to make some guesses about parameters not yet adequately measured. Calculations of inputs (reproduction and immigration) and outputs (mortality and emigration) and knowledge of the way density affects these parameters (density dependence) form the basis of these predictions. In the process of building such models we learn why the population changes and how best to bring about desired outcomes. Demographic models can be relatively fast to establish, so they can offer a first, best guess, of likely outcomes.

The main challenge in developing models for seabirds such as tītī is that they are long-lived and take a long time to mature (Warham 1996). Once mature, they breed slowly so it takes a long time to get a good estimate of parameters (Warham 1996). Population trends may be imperceptible or slight when viewed over short time spans. Population changes observed over the first ten years of our study (and the changes noted by muttonbirders over their life-times) may be determined by the ecological events predominating for the 20 years prior to our observations of current breeding and survival rates. Lagged effects are likely if the age structure of the population has been affected by such past changes, and if breeding and survival are age dependent. The frequency of food failure events, trend in fishery bycatch levels, and the levels of the harvest in preceding decades are therefore important potential determinants of the population trends we note now. Therefore we will place considerable emphasis on an historical analysis of these parameters. The final simulation model of the trends in population observed over the ten years will incorporate our estimates of these other parameters for the preceding 40 to 50 years.

We will use the monitoring approach to challenge and test the accuracy of the demographic prediction approach. Results from the monitoring will provide only an approximate "external check" of the demographic model within the first 10 years of the study. A full "external check" of the demographic prediction model can only emerge in the 20 to 30 year time frame, so our goal in this first 10 years is to prove the methods and test their statistical power, and to provide a strong initial baseline against which to compare future changes. A "step-down" to less frequent monitoring after our first 10 years of the research is envisioned, coupled with an "active adaptive management" approach (Walters & Holling 1990, Ludwig *et al.* 1993, Parma 1998) to further test the validity of the model's predictions.

Comparing variation in bird density on harvested & unharvested areas: a rapid first check for harvest impacts

An additional check for major impacts of harvest on tītī abundance will come from a comparison of the current bird density on harvested and unharvested islands. If a major impact of harvest is occurring this should be reflected in lower average tītī abundance in harvested compared to unharvested areas, or between heavily harvested and lightly harvested *manu* (family harvesting areas). These comparisons will only test harvest impacts if:

- it is safe to assume that the densities of harvested and unharvested islands were roughly the same at the outset of harvesting. The interpretation will be confounded if some other ecological factors (e.g. vegetation, substrate type, and island size) influence bird abundance, and if that factor is present more in the harvested or the unharvested areas. Also, harvesting may have been concentrated initially on areas with higher abundance.
- differential immigration and emigration rates do not obscure comparisons between areas (harvesting may then be causing a decline in abundance in all areas simultaneously, and no difference in density would be apparent between the harvested and unharvested areas)
- spatial variation within each treatment group is sufficiently small that our test of the null hypothesis (of equal density between groups) has sufficient statistical power.

These caveats mean that it would be unwise to rely on this last test of the harvesting impacts alone. However the spatial comparison does allow a rapid first check on the overall thesis of harvest impacts, and a first external check on the validity of model predictions.

Population monitoring: both actual density and trend in density matter

Our research must consider impacts of harvest on absolute density (number of adults or chicks per hectare), as well as on the long-term trend in density (relative abundance). The latter is the most important for the muttonbirders because it signals the long-term sustainability of their harvest. But the former is also of interest because it probably dictates the rate of harvest and benefits in relation to costs of harvesting. Current density is also potentially an important factor for other aspects of island management and conservation such as soil formation, aeration, nutrients and water retention, and regeneration of vegetation. Accordingly, if harvesting causes a lowered but stable population abundance this may still have a cascade of effects on island ecology.

Units of replication

The manu is the fundamental Māori management unit employed on most of the islands, so it is important that the research design uses and mirrors this unit of sampling for most of the questions we ask. Management style and harvest intensity vary between *whānau* on the same island. However, neighbouring manu may not be statistically independent for some ecological comparisons. For example, tītī density, inter-annual fluctuations in growth etc. may vary together amongst manu on the same island because the birds feed in similar areas, are affected by the same local weather variations, and/or individuals hatched nearby may recruit on the other side of the local manu boundary. Therefore care is needed to avoid pseudo-replication by using measures from several nearby manu within the same island as the unit of replication for some ecological questions.

It is important to divide our sampling and study design into two quite distinct periods and methods. The *nanao* extends from the 1st to around the 20th April, when the muttonbirders work in daylight to extra chicks from their breeding burrows. This is followed by the *rama* when muttonbirders traverse their manu at night by torchlight and catch chicks that have emerged from breeding burrows to lose down and exercise wing muscles. Some harvesters only take birds during the rama, and each style of harvest has quite distinct constraints and ecological features, so the research must understand determinants of both modes of harvest.

Inter-annual variation in many population parameters is expected, so each year is another important unit of replication for many of our study questions. Large fluctuations in the quality (size and weight) and number of chicks from year to year are reported by the muttonbirders. Many chicks starve in *kiaka* years. Fat chicks are valued much more than thin chicks by the muttonbirders so study of the occurrence of kiaka years is of intense cultural interest. Analysis of counts of the number of dead sooty shearwaters washed up on beaches (OSNZ "Beach Patrol" counts; Hamilton & Moller 1993, 1995) suggests that there are also major fluctuations amongst years in the survival of adult birds. These poor years must be understood because they are enormously important for tītī population dynamics (Hamilton & Moller 1993, 1995). Kiaka years may result from food supply failure (Oka *et al.* 1987), but more specifically they reflect poor provisioning of chicks, and the latter may be affected by unsuitable wind conditions that make it energetically inefficient for the adults to return to feed their chick. The wide variation in chick numbers and size amongst years makes it important that all variables and averages are measured for several years. Our study will review all recorded measures of inter-annual variation in parameters and measure them for each of the first three years on our own study areas.

There is probably a continuum from poor to excellent chick growth and survival, so the research team will avoid a binary division between "good" and "bad" years whenever possible. Nevertheless the research strategy will be to gain detailed information on at least 3 good to high quality years before performing a power analysis to determine how many good years should be monitored for each variable. Since these years are the most frequent, they are the primary focus of our research. We obtained excellent observations in 1997 of a moderately poor harvest season, but hope to also sample an extreme kiaka year sometime in the next 6 years. Kiaka years are thought to occur about every 5 years (M. Jones, J. West, pers. comm.). We will complete a 3rd year of intensive study of harvest rates and chick movements and activity during an excellent harvest season in 1999, and thereafter will repeat the intensive sampling in one more poor year sometime in the remaining 5 years. The aim is to have two kiaka years and at least three good chick years for comparison.

STUDY AREAS

A mix of intensive and extensive approaches

There is as yet insufficient information on movement rates between the populations to determine how ecologically and demographically independent each breeding colony is between different islands, or within the same island. In the meantime we have designed a hierarchical sampling strategy where we will take regular and intensive measures on several manu on one harvested island (Putauhinu) and on 3 unharvested islands (Whenua Hou, the Snares and Taiaroa Head on South island), complemented by several less intensive one-off samples from several other harvested and unharvested islands. There were also two years of intensive sampling of harvesting on Poutama Island at the beginning of our study that will assist overall replication of our findings (Lyver 1999).

Harvested study areas: intensive study on Poutama and Putauhinu Islands
Intensive study of harvesting began on Poutama Island in the 1994 harvesting season. This was to have been our long-term intensive study area, so we invested considerable effort in banding adults and chicks there for long-term measures of survival, recruitment, and age at first reproduction (Table 1). Approval for the long-term study on Poutama was withdrawn part way through the 1995 harvesting season by the whānau harvesting there. This forced rapid re-adjustment of the study questions pursued by Phil Lyver in the remainder of his PhD (emphasis shifted from temporal comparisons to testing some TEK constructs concerning spatial variation in birds and harvest pressure).

The support and guidance of Jane Davis and her whānau led to the research team approaching all the whānau harvesting on Putauhinu Island in 1996 to gain approval for making this our new long-term intensive study area. Little research was done in the 1996 harvesting season, although chicks and a few adults were banded on the "Main Point" area of the Davis manu (Table 1; Appendix 4).

The Davis whānau allocated a 40-m x 20-m harvested area of their manu for the research team to establish inspection hatches, monitor bird behaviour etc. This area is designated as the "Davis Rahui" in our data records. As this area is very small and surrounded by harvested ground, it is questionable if it can be used as a true non-treatment comparison. The *rahui* greatly assists the research because it allows us to establish inspection hatches through which we can regularly extract chicks for measuring and to measure burrow occupancy, but unless subsequent research shows very limited movement of the birds from their natal burrow, we expect that it will be designated as a treatment block.

The Davis Rahui area will be used as one measure of population abundance, but the main way that population trends on Putauhinu will be re-assessed will be by annual resurveys of 46 transects spread around 3 of the manu.

Harvested study areas: an extensive survey
The intensive studies every year on Putauhinu Island must be complemented by short, one-off visits to a variety of other harvested manu in order to replicate our findings. These visits are invasive for the muttonbirders. The research's success is critically dependent on the muttonbirders' co-operation. Accordingly, we can not predetermine nor guarantee how many other islands or manu can be surveyed in this manner. We hope to sample at least 6 islands and 20 manu. The Rakiura Tītī Islands Committee has given its sanction to this extension and its members will encourage (but not coerce) individual whānau to participate in the extensive phase of the study. The first of these extensive survey samples was successfully completed at Mr Ron Bull's manu on Taukihepa in the 1999 harvesting season. A power analysis in 2002/03 of all spot sampling measures will be performed to check that 20 manu will be adequate, or whether fewer would be sufficient to answer the main questions asked in this extensive survey.

Each of the 20 manu will be visited for about 7 days by two researchers. At least 3 (but hopefully 6) manu will each have ca 10 permanent transects marked within which burrow entrance density and burrow occupancy will be assessed using a burrowscope. Burrow entrance density will be assessed by a more extensive stratified random selection of plots (two hundred 2m-radius circular plots). Fixed transects will be revisited and re-measured after 10 years to assess population trends on harvested islands. Data from the 3 - 5 manu on Putauhinu will be pooled with these additional study areas for this trend analysis.

Islands differ according to whether they have weka (*Gallirallus australis*), kiore (*Rattus exulans*), ship rats (*R. rattus*) or Norway rats (*R. norvegicus*) present, or none of these potential tītī predators

(Appendix 1). Although they are known to kill chicks, their respective impacts on tītī population trends are unknown. As far as is practicable, we will stratify our extensive sampling according to each predator's presence or absence.

There are four main clusters of Tītī Islands: the south-west Rakiura group where our intensive studies are centred), the southern and south-eastern group, and the north-eastern group (Fig. 2; Appendix 1). The research team will attempt to stratify its sampling between these areas in case ecological factors vary between groups.

Unharvested study areas without predation of adults by introduced mammals

An area on Putauhinu on the Kitson block has not been harvested for 30 - 40 years (Jane Davis, Paul Lee, Jasmine and Billy Fisher; pers. comms.), and the whānau currently harvesting on Putauhinu have generously agreed to designate it as a rāhui site for our study purposes. An area approximately 70m x 50 m has been marked off and is called the "Kitson Rahui" site in our records.

The Snares is an important non-treatment site because it represents the only high density, large, and unharvested tītī colony without potential predators in the southern region of New Zealand. Prior tītī research there by the Department of Zoology, University of Canterbury, presents the prospect of some comparisons of recent density with measures in the 1970s and 1980s, as well calculations of survival and recruitment of chicks banded 2 - 3 decades earlier. The main disadvantages of monitoring populations on the Snares include quarantine risks and its sensitivity as a pristine Nature Reserve (The Department of Conservation aims to keep visits to an absolute minimum), the expense of transportation to and from the island, and its relative distance (100 km) from the centre of the islands that are harvested. The further the distance between treatment and non-treatment islands, the more likely that feeding, wind, or climate conditions might vary between them. If any agent is depressing or increasing bird numbers on a local scale, this large distance between the Snares and the harvested islands could confound the use of the Snares to partition the impacts of harvest on populations. On the other hand, if research identifies a much broader impact on bird numbers (such as northern hemisphere or equatorial climate fluctuations), then the large distance between the harvested islands and the Snares strengthens its use as a measure of population consequences independent of harvest.

Whenua Hou (Codfish Island) has been chosen as a non-treatment island because it represents the largest population of unharvested birds close to the Tītī Islands. Access is comparatively easy, though DoC still wish to limit visits there to the minimum necessary. The main priority of DoC for the island is to support the Kakapo (*Strigops habroptilus*) recovery program (Roberts 1994). This means that the monitoring of tītī on Whenua Hou may be disrupted from time to time when Kakapo breeding precludes visits to study tītī breeding. Another complication of the choice of Whenua Hou includes the way potential predators of tītī have recently been eradicated. Weka were removed in 1984, possums (*Trichosurus vulpecula*) between 1983 and 1987 (Roberts 1997). Kiore eradication was attempted in 1998, but it is unknown as yet whether it has been successful. This has unknown effects on population trends and absolute density, and any population growth that we observe now may be constrained (e.g. breeding age structure effects) or enhanced (e.g. through relaxation of density dependent influences on reproduction and mortality rates because density was previously lowered by predators). An advantage of using Whenua Hou for our study is that monitoring of 50 tītī study burrows there has been performed annually by the Department of Conservation since 1986 (see Hamilton *et al.* 1996 for a summary of this monitoring and the way our team greatly extended the study intensity). DoC requested that we take over this monitoring within our own program.

One moderately large colony of tītī exists on Tuhawaiki Island, a near-shore islet in the Catlins region (Fig. 4; Hamilton *et al.* 1997b; Hamilton 1998b). Only 50m of water separates the islet from the mainland, and this is well within the known swimming range of stoats (*Mustela erminea*), and possibly also Norway rats or ship rats. However in 4 years of monitoring on Tuhawaiki we have never detected sign of mammalian predation of tītī (Bettany 1998; Hamilton, 1998b; Lyver, in press; Lyver *et al.* subm.; Uren, 1999). Perhaps the strong current in the channel and lack of forest on the island deters stoats and rats from using it? We have therefore tentatively designated the islet as an unharvested colony without predators. The islet is also distant from the main harvested island, is covered in introduced grasses and bracken rather than muttonbird scrub, and its soils are not as rich or friable as on the Tītī Islands themselves. Accordingly it represents a somewhat atypical non-treatment colony, but a valuable area for testing techniques (e.g. Uren 1999) and measuring breeding success in the absence of predators (Lyver *et al.*, subm.).

Choice of suitable unharvested (non-treatment) study areas closer to the harvested islands was difficult because only very small stacks or islets are not harvested, and access to these on a regular basis is practically impossible. Nevertheless we aim to visit 6 such small colonies to monitor burrow entrance density and burrow occupancy in much the same way that we are doing on harvested manu outside Putauhinu. These one-off visits will be used together with measures from the regularly monitored non-treatment areas listed above for comparison of bird density in harvested and unharvested areas.

Analysis of the results must take account of the potential effect of island size itself in influencing population density. Ecologists studying Procellariids often choose very small islands to facilitate measures of recruitment and immigration (Richdale 1963, Serventy 1967, Wooller *et al.* 1988, Bradley et *al.* 1991, G. Taylor, *in lit.*), but small island size may alter these very parameters. Accordingly we will use island size as a co-variate in any comparison of density between harvested and non harvested areas, and will try to ensure that a range of large and small non-treatment islands is included for comparison.

Unharvested study areas experiencing predation of adults by introduced mammals
Inclusion of monitoring sites on the South Island mainland (Fig. 3) is valuable because strong impacts of predation of adult tītī by stoats, ferrets (*M. furo*) and feral house cats (*Felis catus*) are expected (Hamilton & Moller 1993, 1995; Bettany 1998, Hamilton 1998b, Lyver *et al.* subm.). Population trajectories are therefore expected to be quite different at these sites, and this will help calibrate and check the demographic model.

Reduction in funding from FRST from July 1998 has forced elimination of the ongoing monitoring of most of the mainland sites from the 1998/99 breeding season on. We have however dedicated University of Otāgo research assistance funds (awarded to Henrik Moller) to keeping banding and survival estimation going at the Taiaroa Head (Private) colony, while eliminating regular measures of breeding success from the colony. This is our most continuously studied area (regular banding since 1992; Table 1; Appendix 3), and natal young are now returning to breed in the colony. It is important to keep research going there to obtain the earliest possible measure of age at first reproduction. The monitoring of burrow numbers and the proportion occupied at these mainland sites (Fig. 3; Appendix 3) in the early years of the study already provides a baseline of colony population size. We will seek funding to remeasure colony population size in the last 3 years of the initial 10 year study.

A restoration program involving imposition of predator controls on some of these mainland sites is planned (Jones *et al.* 1997), but its scale and timetable are dependent on finding suitable funding. If it can be mounted, the subsequent rate of resurgence of these artificially small colonies (i.e. numbers have been lowered by predators) will provide a valuable check on the demographic model, density dependence, and an independent measure of the rate of immigration to the sites.

Table 1: **Numbers of Sooty Shearwaters banded in each year of study by the *Kia Mau Te Tītī Mo Ake Tōnu Atu* research project.**

Colony	*1992/93*	*1993/94*	*1994/95*	*1995/96*	*1996/97*	*1997/98*
Mainland colonies						
Taiaroa Head (Private)	-	475	341	367	93	287
Nuggets	23	0	172	0	7	11
Tunnel Rocks		2				
Kakanui	-	-	36	0	0	2
Long Point	-	5	0	0	0	0
Island colonies						
Tuhawaiki Island	15	11	24	0	38	105
Poutama Island	-	1482	1662	-	-	-
Snares A	-	-	-	-	1030	739
Snares B	-	-	-	-	629	170
Snares C	-	-	-	-	299	44
Snares D	-	-	-	-	190	230
Snares transects	-	-	-	-	311	n.a. yet
Snares miscellaneous[3]	-	-	-	-	144	0
Whenua Hou A	-	-	-	-	106	95
Whenua Hou B	-	-	-	-	31	46
Whenua Hou C	-	-	-	-	23	52
Whenua Hou transects						

[3] Miscellaneous - sites not associated with monitored plots. They include tracks and areas around huts.

Putauhinu transec	-	-	-	-	n.a.	n.a.
Putauhinu Kitson rahui	-	-	-	-	n.a.	n.a.
Putauhinu Davis rahui	-	-	-	-	n.a.	n.a.
Putauhinu Main Pt	-	-	-	318	n.a.	n.a
Putauhinu Jane's gully	-	-	-	-	n.a.	n.a.
Putauhinu miscellaneous						
Taukihepa (Bull Manu)		173				
Solomon Island		50				

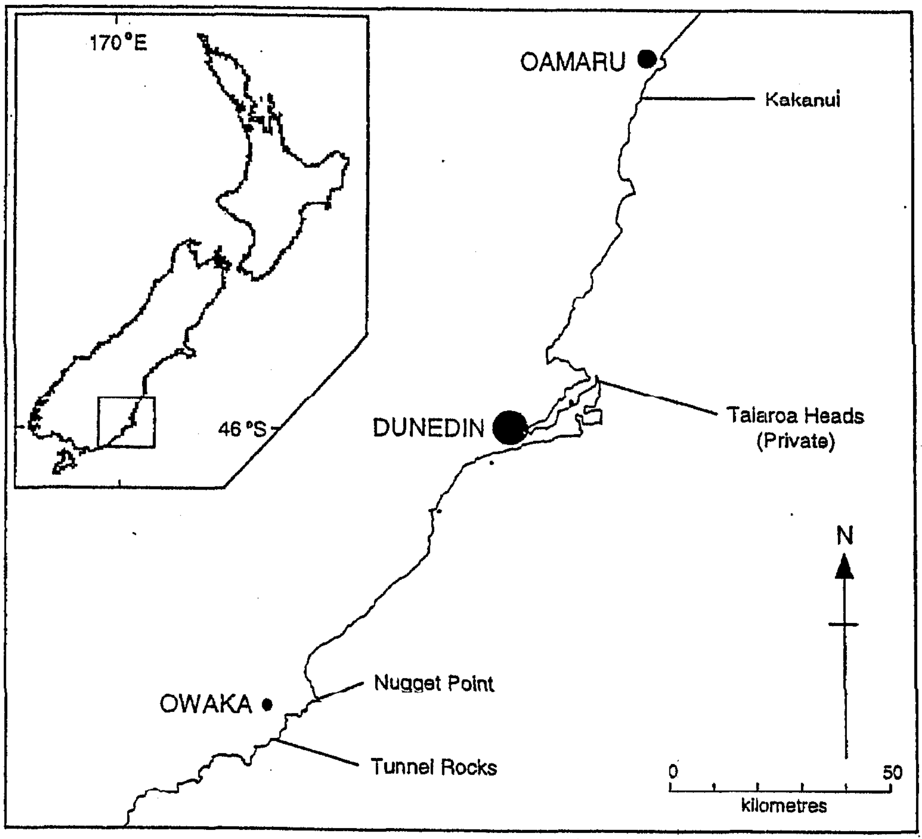


Fig. 3. Location of tītī breeding colonies on the South Island mainland and near-shore islets which have been monitored between 1991/92 and 1997/98.

SUSTAINABILITY OF HARVESTS (OBJECTIVES 1-3): RATIONALE & METHODS

A mix of quadrats and transect sampling methods
The dual role of the monitoring plots is to (i) provide a measure of population abundance and (ii) to measure breeding success, proportion of adults breeding, size of chicks, and recruitment.

Large quadrats are convenient for measuring local population densities, marking a high proportion of the adults and chicks (to facilitate estimation of survival and recruitment) in one place, measuring philopatry (fidelity to a single burrow, and recruitment of young near to their natal burrow), and estimating the proportion of adults breeding. Large sample sizes can be obtained relatively quickly from study burrows aggregated into large quadrats. The disadvantage of using large quadrats is that they can not take account of local spatial variation in the parameters such as egg and chick survival, which might be affected by local vegetation, soil and drainage conditions. The research program is aiming to measure average input and output parameters for each manu and island, so some form of spatial replication is needed. Accordingly we have measured burrow density and occupancy, and breeding success on both quadrats and a series of more widespread transects within Putauhinu, Whenua Hou and Snares (Table 2).

All transects and quadrats are permanently marked so that repeated measures have the strongest power possible to detect temporal changes in the parameters of interest.

Quadrat size and layout
There are 3 quadrats on the Snares (Fig. 4), 3 on Whenua Hou (Fig. 5), and 2 on Putauhinu (Fig. 6). Where-ever possible the maximum quadrat size was chosen to include 300 - 400 burrow entrances (Table 2). This was targeted on the expectation from previous mainland work (Hamilton 1998) that about a third would be occupied in any one season and that about 100 pairs would be ideal for robust estimates of proportion of non-breeders, breeding success etc. On the Snares, where the breeding colony is continuous, the quadrats were approximately 20 - 22 m square. On Whenua Hou quadrat Alphonse A (116 burrow entrances) is ca 90 m x 40 m, but Alphonse B (ca 30 m x 40 m) and Alphonse C (ca 10 m x 60 m) covered the entire colony in the vicinity. On Putauhinu the size of the Davis Rahui quadrat (40 m x 20 m) was limited because it restricted the harvest opportunity of the whānau, whereas the Kitson Rahui quadrat (ca 60 m x 25 m) was chosen to contain about 400 burrow entrances.

Work routines established on the Snares in the 1996/97 and 1997/98 seasons were too strenuous because of equipment failure, delays in getting to the island, exceptionally wet conditions (1997/98) and restrictions on numbers of workers. This prevented completion of burrowscoping of all the quadrats in both 1996/97 and 1997/98. Analysis of the spatial variation in both the burrow occupancy (eggs/entrance) and breeding success (chicks/egg) showed that the variation between blocks is large enough to make the analysis fairly robust to the choice of number of burrows sampled per block. In particular, estimation of the between- and within- block variance components led to the prediction that for both of these indices, the standard error of the mean should be virtually unchanged if the current number of burrows sampled per block was halved. For example, using the data for the 1997/98 season, the variance components for burrow occupancy are 0.102 (between blocks) and 0.387 (within blocks). This led us to predict that the standard error of the mean burrow occupancy would be 6.2% if we sample 150 burrows per block rather than the ca 400 present within the quadrats.

Table 1. Number of quadrats and transects monitored on each breeding area. The Olearea forest type is divided into 'fern' (>30% ground cover) and 'open' on the Snares and Putauhinu (all areas on Whenua Hou had > 30% fern ground cover).

Colony	**Total of burrows 1997/98**	**# Burrows (# transects)**			**# Burrows in long-term plots 1997-98**		
		Poa	**Olearia (open)**	**Olearis (Fern)**	**A**	**B**	**C/D**
Snares	2063	300 (15)	300 (15)	300 (15)	333	403	427
Whenua Hou	733			320 (16)	184	111	116
Putauhinu	200		100 (5)	100 (5)	ca 140 (Davis rahui)	ca 400 (Kitson rahui)	

A full power analysis to assess the chance of detecting trends in these indices cannot be carried out until we have data from the third season because data from only two seasons cannot give us any indication as to the potential temporal variation to expect in the absence of any trend. However large this temporal variation, the results above implied that we could safely reduce the number of burrows sampled per block without compromising the precision of the study. Accordingly we halved the size of the Quadrats on the Snares for the 1998/99 season.

"*Poa*" transects on the west coast of the main Snares island are in areas of either pure *P. astonii* or *P. tennantiana* while those on the south side of Hoho Bay are in pure *P. tennantiana*. Conditions under these tussocks differ considerably and may well affect burrow density etc., so variation between transects will be looked for in the analysis. Also, historical changes in vegetation may still be affecting population processes in some of our transects. For example, on the south side of Hoho Bay some of the transects in what is now *Poa tennantiana* were under *Brachyglotis* forest until 1976 (P. Sagar, pers. comm.).

The selection and layout of the main study quadrats at Whenua Hou is given in detail by Hamilton *et al.* (1996). One of the quadrats (Alphonse C) was placed over the area containing 50 study burrows monitored annually since 1986 by DoC research teams. Alphonse A and B were chosen as (a) being conveniently positioned along the Alphonse track (which is relatively close to the research hut), (b) being well out of the zone frequented by Kakapo (required by DoC so that our study did not disturb this critically endangered species), and (c) containing a reasonably defined aggregation of breeding burrows.

Transect layout and size

Forty-six transects are currently marked on Putauhinu. Half were placed in "closed" areas with >30% ground cover of ferns, the others in "open" (<30% ground cover). On the Snares 15 transects are marked in *Olearia* with no undergrowth, 12 in *Olearia* with fern undergrowth, and 15 are in areas of *Poa* tussock grassland with no canopy (Fig. 4), a habitat that hardly occurs on the Tītī Islands (*Poa* was included in Christine Hunter's PhD study to broaden her comparisons of breeding success and population density amongst habitats). All transects are in closed areas on Whenua Hou (open manu does not occur). Transects were placed randomly along the South Bay and Rogers Head and Alphonse tracks in areas containing burrows (Fig. 5).

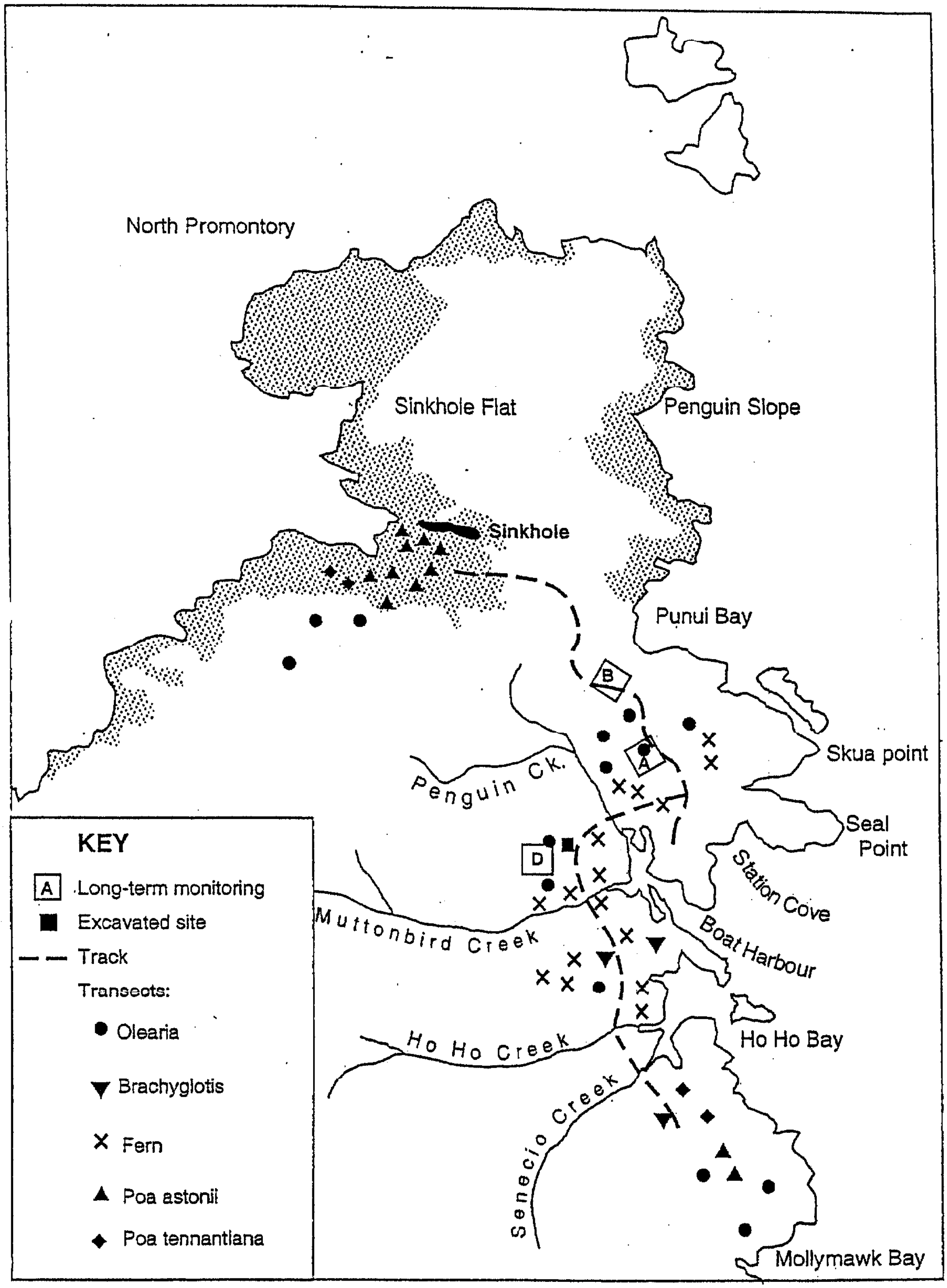


Figure 4: Layout of main study quadrats and transects at the Snares.

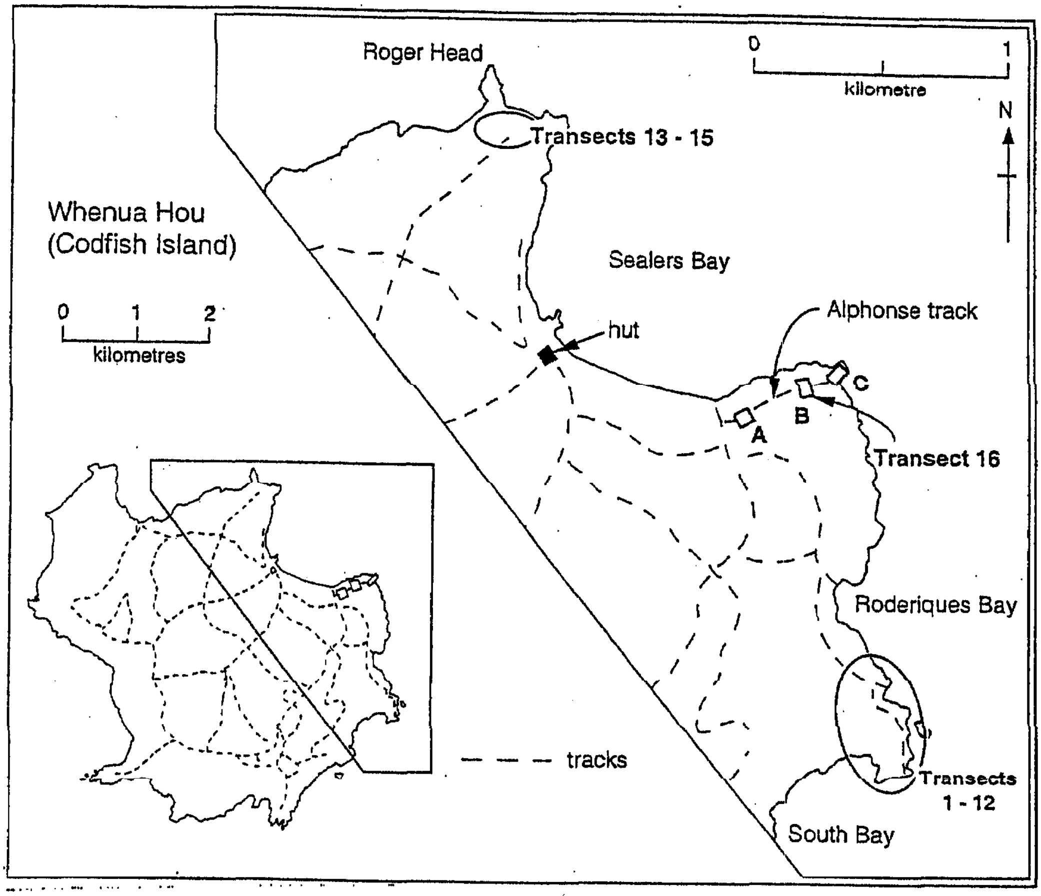


Figure 5: Layout of main study quadrats and transects at Whenua Hou.

Each transect's starting position was chosen randomly and a cord drawn out along a randomly chosen compass bearing. The first 20 burrow entrances encountered within 1 m either side of the cord (all sites except Whenua Hou) were included within the sample and the distance to the 20th was measured. On Whenua Hou low density of entrances forced use of 2m either side of the central line. Entrances overlapping the edge of the transect were only included if the mid-point of the entrance hole fell within the 2m or 4 m belt. The transect length was extended to replace any entrance hole becoming closed between seasons, unless a new hole had already appeared within the belt transect during the same period.

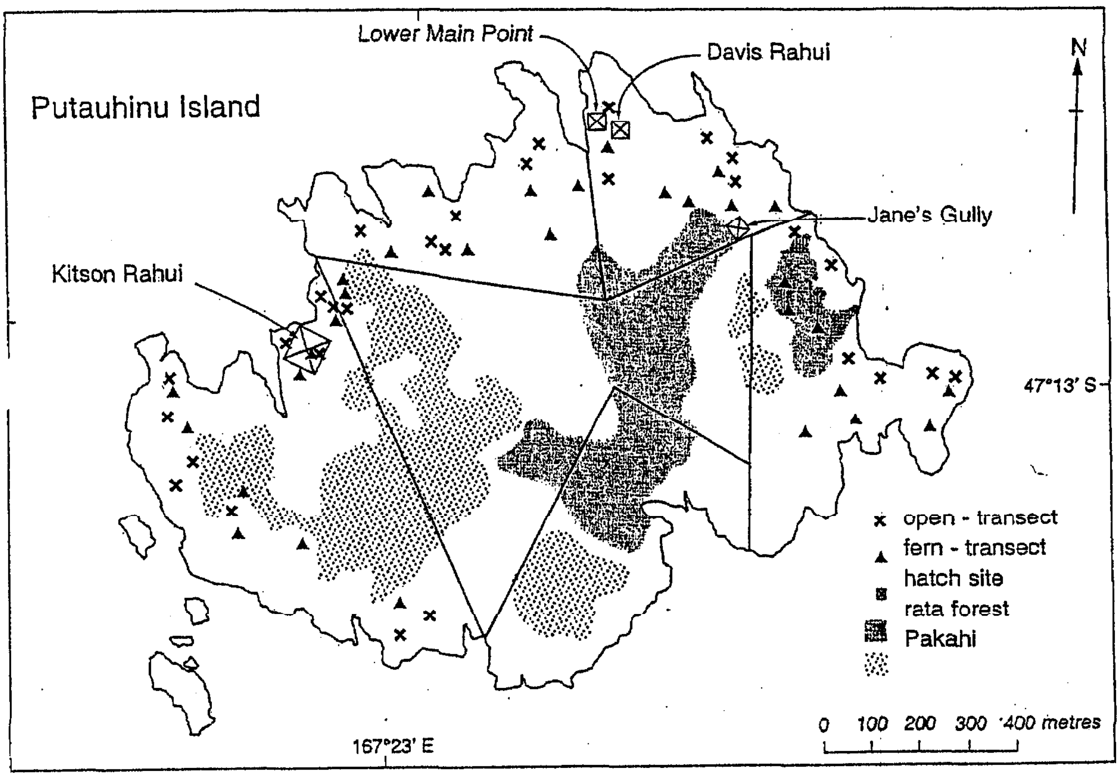


Figure 6: **Layout of main study quadrats and transects at Putauhinu Island.**

Periodicity of sampling
Occupancy of the burrows in the quadrats will be measured every year. The transects will be monitored in the first and last 3 years of the first 10 years of intensive study to detect trends in population abundance for the monitoring approach, and to check that the trends occur about equally in all parts of each island. In the intervening 4 years burrow occupancy and breeding success will be measured only on the large quadrats (mainly using inspection hatches over nesting chambers). If the trends and breeding success measured on quadrats and transects are about equal, the transects will be abandoned altogether for the long-term project after 10 years.

Occupancy of burrows within quadrats at Whenua Hou and the Snares is determined by burrowscoping 3 times within each of the first 3 years of study: (i) just after egg laying, (ii) just after hatching, and (iii) just before fledging every year. Occupancy within burrows in the transects was measured in these same

3 periods in the 1996/97 and 1997/98 seasons, but only for the first and last periods in the 1998/99 season. It is envisioned that only the first and last survey will be done for the middle 4 years of the study, before re-instating the middle check around hatching for the last 3 years. This design saves labour in the middle years when the main focus of the overall study will be on breeding periodicity and survival of adults, but still allows us to check the expectation from other studies of Procellariiformes breeding that very few losses occur after the egg stage (Serventy 1967, Serventy & Curry 1984, Warham 1996).

Rakiura Māori tikanga prevents people "from setting foot on the manu" before mid March (the mid to late chick phase), and after the 31 May (by which time fledging is complete). This centuries old rahui is an important part of TEK which is thought to minimise disturbance of the birds and the ground (Lyver & Moller 1999). Warham *et al.* (1982) also emphasised that tītī were prone to disturbance in the egg phase, and this is believed to be a common phenomenon in Procellariids (Serventy & Curry 1984, Warham 1996). This rahui prevents study of egg and early chick survival on the harvested islands. It is the most fundamental alteration of our study design because of its tikanga Māori approach. Accordingly we rely on egg and early chick survival estimates from unharvested islands in our mathematical simulation models. We are also assessing the potential importance of disturbance by comparing the breeding success in burrows monitored frequently and infrequently in the Snares and Whenua Hou in the 1998/99 breeding season.

Burrowscoping to determine burrow occupancy

Initial tests of determining burrow occupancy from methods used by earlier workers (smell and signs at the burrow's entrance) proved unreliable (Hamilton 1993, 1998b). Therefore a burrowscope (based on the design reported by Dyer & Hill 1991) was used to determine burrow occupancy and breeding success. Successive improvements of the design led to the version finally used in our study from the 1997/98 season onwards (Lyver *et al.* 1998).

The burrowscope consists of a miniature video camera mounted inside a ring of infra-red LED lights on the end of a 3 m long flexible tube. One of the operators (the "augerer") extends their arm into the burrow entrance to push the tube along the burrow while another (the "monitorer') observes a VDU attached to the other end of the tube. The monitorer guides the tube down the burrow, around corners, roots and rocks by instructing the augerer to twist the tube left or right, withdraw or push it forward. A handle at the monitor end is worked to flex cables within the tube that manipulate the orientation of the camera head to the left or right, or up and down. With practice and considerable patience the operators can negotiate up to 3 m of burrow length, but sometimes obstructions or sharp corners make it impossible to fully prospect the burrow, especially beyond 2 m from the entrance (Hamilton *et al.* 1997a, Lyver *et al.* 1998). If the entire burrow can be prospected, the burrowscope operators can score whether or not an adult bird (or birds) is (are) present, whether an egg has been laid and hatched, and whether a live chick remains.

We gained several clues that the burrowscope may not be accurate in detecting eggs and chicks within burrows as the 1995/96 season progressed. We therefore dug up a plot of burrows ('Snares C') that we had first burrowscoped 3 times (Hamilton *et al.* 1997a, 1998; Hamilton, in press). The experiment confirmed that several eggs were undetected by the burrowscope and some were counted twice from different burrow entrances. This presents several methodological challenges for our study which will be investigated as soon as financial resources allow. The kaitiaki for the study have forbidden the digging of any burrows to directly test the biases in detection by the burrowscope (disturbance of the ground is an important part of their tikanga and kaitiakitanga), at least until all other avenues of measuring the biases have been trialed. Re-colonisation of the excavated plot on the Snares will be monitored each year to assess whether damage to the manu causes a long-term reduction in its use by birds. In the meantime we will perform a series of random dummy egg placements (inserted through inspection hatches placed over nesting chambers), followed by prospecting of the burrow from the normal burrow entrance using the burrowscope (see de Cruz *et al.* 1998 for the details of the design). The burrowscoping team will not know which burrows have eggs, nor how many eggs are present. Replications of these tests will be done on The Snares, Putauhinu, Whenua Hou, and one mainland colony between late May and early October when all the birds have left so that natural eggs, chicks or adults do not interfere with the trial. We will build a multiple logistic regression model to predict the probability of detection of the egg from location, burrow entrance density in the vicinity, habitat, and characteristics of the burrow that can be determined from the entrance (length, degree of turning, bifurcation etc.). We hope to use this model to correct biases in our regular surveys of egg and chick occupancy.

Use of Whakaputa, study hatches and puru: do they affect burrow occupancy?
Whakaputa is the Māori term for a hole dug over a nesting chamber to extract a chick (Ashwell 1999). An earthen plug, called a *puru* is placed into the whakaputa after the removal of the chick to ensure that the nesting chamber remains dry and re-usable in future seasons. Researchers often use wooden, plastic and stone inspection hatches over holes dug above the nesting chamber of Procellariids to facilitate egg and chick observations. They greatly speed survey work and therefore have the potential to facilitate the research. However, the appearance of a hole above the nesting chamber may cause the tītī adults to dig further next year, or even to abandon the burrow altogether. Thermal properties of the chamber might repel (or even attract) birds to nest under the hatches. Any of these effects would preclude the use of hatches over nesting chambers to estimate long-term trends in population abundance. Therefore, we have instigated a trial of comparative occupancy of chambers for which there was no hole dug (burrowscoped only), where a wooden or ceramic tile hatch was placed over the hole, and where a puru was used to block the hole. Chambers were allocated randomly to these three treatment types at Whenua Hou and the Snares. They were monitored again in the 1998/99 breeding season to complete a 3 year check on occupancy changes.

If no changes in relative occupancy of the 3 types of nesting chamber are apparent, we will convert as many of the chambers over to having inspection hatches as are needed for the study. From then on population monitoring will be done entirely by lifting the inspection hatches. If the use of hatched burrows goes up or down compared to unhatched chambers, we will persist with the much more laborious method of using burrowscopes, and keep use of inspection hatches to an absolute minimum.

Estimating harvest intensity
The total number of chicks available to harvesters will be calculated by multiplying (i) the area of each manu (measured by Global Positioning System fixes of the perimeter of the whānau's manu), (ii) the number of entrance holes per m^2 on quadrats or transects within each manu, (iii) the proportion of the entrance holes that have one or two chicks before the beginning of the nanao (measured by burrowscoping along transects), and (iv) the proportion of the chicks that are above kiaka (reject) size.

Estimation of the proportion of chicks harvested on each manu in the nanao and the rama will be calculated by dividing the tally of chicks harvested in the nanao and rama by the estimates of numbers available from above.

Poutama and some other islands operate on an open manu system (there are no separate whānau "harvesting territories"). For such islands only a single estimate of harvest intensity can be calculated using the extent of the area of the whole island and the combined tally of all the muttonbirders present in those seasons.

We will use measures of annual variation in chick abundance on fixed transects and quadrats at Putauhinu, The Snares, and Whenua Hou to factor out (statistically account for) temporal effects on bird density measured during one-off visits to other manu for the extensive study (See pages 19 - 20). Provided that a tight statistical relationship in inter-annual variation in burrow occupancy occurs amongst different islands, we will be able to estimate the "average" occupancy expected at each of the manu sampled in a single year. We can check this assumption in a variety of ways from our own measures but also have birder's diaries from the past 3 decades to check correlations. This estimate will then be correlated with measures of harvest pressure to calculate an average sustainable yield for each island.

A multiple logistic regression model will be constructed to predict the proportion of chicks harvested on each manu from the density of burrow entrances, occupancy, manu area, number of harvesters, and number of people helping to process the birds. This is the core analysis for the study that relies on the fullest replication that we can achieve (at least 8 islands and ≥ 23 manu with Poutama, Putauhinu and the extensive survey of ≥ 20 manu combined) in the 10 year program.

We will use the multiple logistic regression model to estimate harvest intensity on all other (unvisited) harvested islands from easily measured predictors (like island/manu size, number of muttonbirders catching and helping), and substituting a median estimate for burrow entrance density and burrow occupancy into the model. However there may be too much variation in the latter estimates to make the error limits around the predicted proportion harvested narrow enough to be reliable. If so we will either have to get onto these added islands for a once-off visit to measure burrow entrance density and occupancy, or we may be able to determine the latter variables from the harvest tally per unit effort measured by the muttonbirders themselves using our data form. The exact method used can not be determined until the sampling data from the first series of researched manu are aggregated and variation between sites has been assessed (expected by 2004).

The potential importance of chick and parental quality and selectivity of the harvest
The first simplifying assumption made by most population ecologists is that individual differences in reproductive performance and survival matter little for overall outcomes. However, long-term studies have shown that lifetime reproductive success of short-tailed shearwaters *(Puffinus tenuirostris)* is very unevenly spread between breeders (Wooller *et al.* 1988, 1989, 1990; Bradley *et al.* 1989, 1990, 1991). During the completed lifetimes of 418 short-tailed shearwaters on Fisher Island, 27% of all individuals produced no young and 19% only 1 young. Overall 8% of all birds produced 53% of all the young that returned to Fisher Island to breed and 26% of all birds were responsible for all breeding offspring (Tasmania Parks & Wildlife Service, 1997). This suggests that quality of parents and their chicks, and/or the habitats and places where they breed are important determinants of whether the parents are replaced by their offspring in the next generation.

Muttonbirders report that they prefer larger and more developed chicks. The first studies of the tītī harvest by Phil Lyver (PhD, 1994/95 - 1996/97) demonstrated that muttonbirders on Poutama Island succeed in harvesting above average quality chicks (Fig. 7; Lyver subm. a) by targeting particular areas of the island according to prevailing wind exposure. Combined data from the team, Jane Kitson (PhD student 1996/97 - 1999/2000) and Christine Hunter (PhD student 1996/97 - 1999/2000) will test whether the same selectivity of the harvest occurs on Putauhinu Island. Size, weight, condition (weight for size) and feather development will be used as surrogate measures of chick quality. Variation of thes

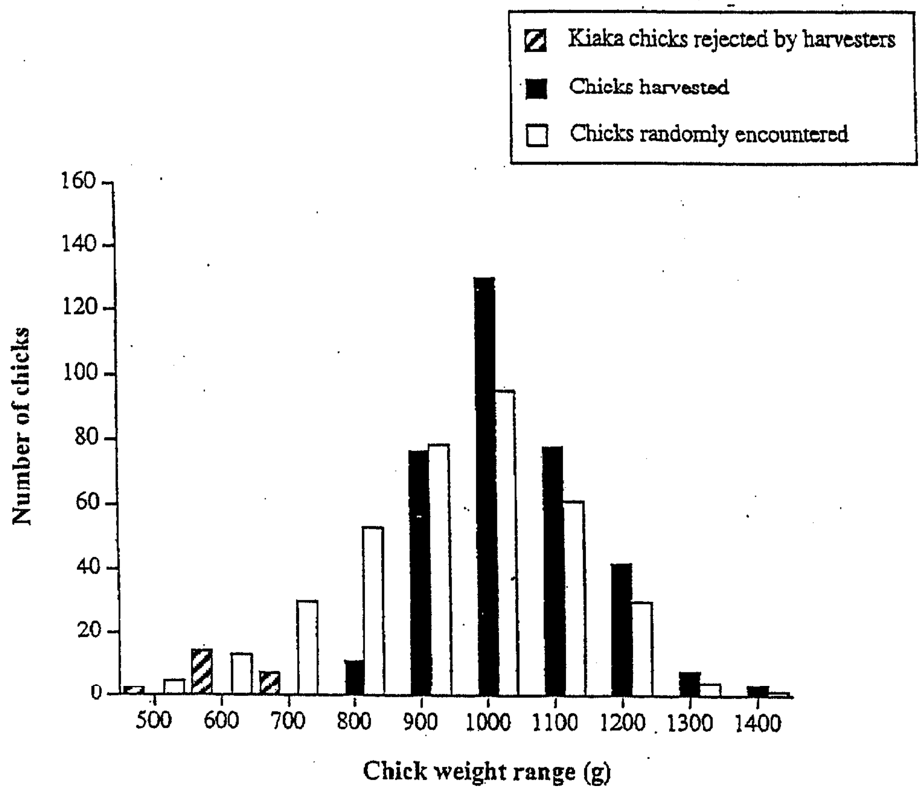


Figure 7. Weights of chicks rejected and harvested by muttonbirders, compared with the weight of chicks randomly encountered by researchers on Poutama Island, 1994 and 1995.

parameters within seasons and between years are monitored at each of 4 areas on Putauhinu where inspection hatches have been placed over nesting chambers. Thirty to forty chicks at each area were banded and measured, and then weighed weekly during the harvest season (1998, 1999). Weight and body condition of these chicks will be compared with the same measures taken on a weekly sample of at least 40 harvested chicks.

Sagar & Horning (1998) showed that heavier chicks banded on Snares Island were more likely to return to breed there, and we hope to re-analyse other data bases from earlier banding to confirm similar effects elsewhere. We will eventually be able to check whether these putative quality measures affect chick survival to first reproduction from return rates of banded chicks after 8 - 10 years of our own research. We will also test whether the time of fledging as well as size affect probability of recruitment, and whether the time of fledging affects risk of being harvested. Finally we will determine whether size and fledging date affect subsequent breeding success once they return as adults to breed. All these potential chick quality effects will be incorporated into a simulation model to quantify the net effect of harvest selectivity on harvest impacts.

Measuring vulnerability to harvest of different quality chicks
Small, 35 g radio-transmitters (Holohil Systems Ltd., Canada) are taped to feathers on the chick's back so that chick location and activity above ground can be measured by an electronic scanner or hand-held antenna. Most of these radios will be lost at sea. By radio-tracking 30 chicks each season (15 of low and 15 of high quality), we can monitor the time of emergence of chicks from burrows during the rama, the time they spend above ground, their movement out of or into refuge areas, and the time they leave the island. These behaviours will be compared for low and high quality chicks to test whether variation causes differential vulnerability to harvest. We have some of these measures for chicks in 1997 (a poor chick season) and 1998 and 1999 (both high chick quality years). If a kiaka year appears before the end of our study we will repeat the radio-tracking then to test links between chick quality and vulnerability (behavioural variation between years should follow changes predicted from our observed variation between high and low quality chicks within a year).

Spatial and habitat refuges from harvest
Preliminary work on Poutama and Putauhinu Islands has highlighted the patchy nature of where some muttonbirders choose to hunt (P. Lyver and J. Kitson unpubl. data). Therefore the existence of spatial refuges from harvest within each manu deserves more attention. We will record where the muttonbirders harvest, identify their preferred habitat, and compare it with all other habitats available on Putauhinu. We will test whether the quality of chicks in the preferred areas is different from randomly selected ones.

Burrow occupancy and quality of chicks are being compared between "open" and "closed" habitat types on Snares, Whenua Hou and Putauhinu. If strong differences between habitats are found in the first three years of the study, sampling will continue to be stratified between open and closed areas. Otherwise this division will be dropped from future sampling.

Radio-tracking data will help reveal the frequency and scale of movement of chicks between refuge and high harvest areas and habitats.

The role of models
Mathematical models have been used to predict fishery bycatch impacts on albatrosses (Moloney *et al.* 1994, Tuck & Polacheck 1995) and impacts of egg harvest on penguins (Shannon & Crawford, unpubl.). All these models make assumptions and approximations for input parameters. The main function of the preliminary models are to clarify how the system works and what most needs to be measured to build better models in future (Starfield & Bleloch 1986). They can not be expected to divine certainty from a paucity of field data (Hamilton & Moller 1995).

We have already constructed a Population Viability Analysis (PVA) model to guide the management of declining and small mainland colonies (Hamilton & Moller 1993,1995) which identified adult survival and immigration rates as the key unknowns for predicting outcomes. A more realistic model for guiding harvesting on large colonies is in a late stage of formulation (Hunter *et al.* in prep.). Our model's structure has been based on the long-term studies of short-tailed shearwaters from Fisher Island in Australia (Serventy 1967, Serventy & Curry 1984, Skira *et al.* 1985, Wooller *et al.* 1988, 1989, 1990; Bradley *et al.* 1989, 1990, 1991, 1995; Skira 1991, Wooller & Bradley 1996). Short-tailed shearwaters are slightly smaller than sooty shearwaters but the two species share several behavioural and demographic features. They are sibling species which are co-dominant Procellariids breeding in the southern hemisphere, undertaking a trans-equatorial migration to the northern Pacific in the Austral winter and spring (Warham 1990, 1996). Use will also be made of the long-term and detailed studies of Manx shearwaters (Brooke 1990) to offer first approximations to input parameters. Successive iterations of the model will substitute parameters for Sooty shearwaters gleaned from Richdale's, Warham's and Wilson's published studies, reworking of earlier banding, and from our own measures as they become available.

It is important that the field research team stays interactive with the mathematical models to speed the development of improved predictions. We aim to provide the most parsimonious and robust model possible by the end of the first 10 years of the research project. We hope that by the end of the first 10 years that the model will be sufficiently reliable to predict outcomes from various potential management options chosen by Rakiura Māori. It could then become an important tool in guiding an "adaptive management" approach (Walters & Holling 1990, Ludwig *et al.* 1993, Parma 1998) to future harvests. If Rakiura Māori decide to alter current harvest practices, monitoring within the adaptive management framework will further test and refine the model itself.

Demographic parameter estimation
Procellariid researchers distinguish between chicks, juveniles (fledged chicks in their first year of life), "pre-breeders" (adolescents that have not yet bred), and adults. The latter are further divided into non-breeders (they have skipped breeding in that year) and breeders (attempting breeding in the current year).

The most important variables affecting rates that tītī enter the model populations are:

- proportion of adults laying
- hatching success
- fledging success
- probability of starting breeding at a given age
- probability of staying at the natal breeding colony after returning there as a pre-breeder
- probability of surviving and returning to natal colony
- immigration rate (number of non-natal recruits appearing at the breeding colony)

The most important variables affecting the rate at which individuals leave model populations are:

- annual mortality rate of breeders
- annual mortality rate of non-breeders
- emigration

Detailed studies of short-tailed shearwaters have emphasised that these vital rates vary markedly with breeding experience ("breeding age") and to some extent with actual age (Wooller *et al.* 1988, 1989, 1990; Bradley *et al.* 1989, 1991). Our preliminary modelling work has shown that breeding age effects have important implications for model outputs, so our final model will probably need to estimate input and output parameters for each breeding age (Hunter *et al.* in prep.).

Population age structure, sex ratios, and the distribution of ages at first reproduction are important emergent properties of the above vital rates. Paul Scofield (PhD study, 1998/99 - 2000/01) is searching for reliable ageing methods that might be able to provide an age structure for the population. If such a method is found and the rate of population change is known, we will be able to build a "horizontal life table" analysis to estimate age specific survival and reproductive rates. If a reliable ageing method is not found, we could only estimate breeding age effects on reproduction and survival once a large number of known-age breeders are banded and have been observed for decades (a "vertical life table analysis"). It is therefore unrealistic to expect that these breeding age specific rates can be measured directly in our study. Accordingly our mathematical models will have to rely on scaling of the observed mean survival and reproductive rates for all breeding ages of tītī against the relative survival and reproductive rates observed for different breeding ages of short-tailed shearwaters (Wooller *et al.* 1988, 1989, 1990; Bradley *et al.* 1990, 1991).

We must measure the mean age at first reproduction of tītī themselves in our study. The published estimate by Richdale (1963), and cited by several other authors, is a guess based on a single datum. We started banding on the Taiaroa Head (Private) colony in 1992 (Table 1) and banded chicks are now appearing there to breed. Our banding of chicks on Putauhinu, Whenua Hou and the Snares did not begin until 1995/96 to replace this sample, so it will take all of the first 10 years of the study to gain replicate measures for mean age at first reproduction.

We are collecting feathers from a large sample of banded birds in the hope that genetic techniques (Lambert & Millar 1995, Millar *et al.* 1996) can eventually be used to establish a sex ratio for the population. Morphometrics appears to be only a very approximate method of discriminating the sexes (Hamilton 1993). Our preliminary mathematical models will assume that the survival of each sex is the same and an equal sex ratio at fledging, unless the sex ratio measured from feathers indicates otherwise. This is equivalent to an assumption that there will always be a male available to mate with and assist any female that starts reproduction. Preliminary models will be for females only.

Preliminary modelling (Hunter *et al.* in prep) has identified the probability of staying at the colony after first returning as a pre-breeder as a key parameter to estimate. Therefore we are refining measures of brood patches to identify breeders from non-breeders, and regular mark and recapture on study plots should allow direct estimation of this parameter for pre-breeders.

The potential importance of density dependence
The existence or not of density dependence is a fundamental research question. Its answer will not only affect the accuracy of the demographic model's predictions, but also indicates whether a declining density of the birds on harvested manu or islands signals probable ongoing decline of the population. If density dependence does not occur, any population decline on harvested areas is likely to continue unchecked (assuming that harvest intensity does not change); but if density dependence is operating, a decline in density may eventually be halted as recruitment and survival rates increase in response to lowered density. The "fishing down" principle used by fishery biologists illustrates the importance of density dependence - a reduction in abundance when there is strong density dependence is no cause for alarm for the long-term harvest. Indeed, from the point of view of a harvester wishing to maximise the harvest opportunity, a reduction in density is expected and desirable.

Spatial comparisons will be used to assess the importance of density on reproduction, mortality, immigration & emigration rates. Despite our best efforts at replication we are not able to measure breeding success, proportion of breeders attempting to breed in a given year, or the probability of starting breeding at a given age for more than 4 - 5 colonies i.e. Snares, Whenua Hou, Putauhinu, Taiaroa Head (a private mainland colony), Mana Island and possibly Tuhawaiki Island. These will provide valuable reference measures at different densities and colony sizes, but by themselves may not offer sufficient replication for a strong test of density dependence. Therefore we will establish wider replication of the general pattern by measuring the proportion of birds breeding at a larger sample of colonies chosen for relatively high and low density. The development of the brood patch and behaviour of the birds will be used to estimate the proportion breeding during short one-off visits to several (target 10) other colonies.

If increasing density delays the onset of reproduction then we predict that the proportion of pre-breeders will go up with increasing density of the colony. If the proportion of fecund adults deferring breeding in a given year increases with density, or if breeding success decreases with increasing density, then a higher proportion of fecund adults will not be associated with an egg or chick. Different forms of density dependence will be modelled to predict the shape of the relationship between density and the proportion of pre-breeders to breeders and the proportion of adults breeding. A match between the observed and predicted relationships will then reveal a plausible first approximation to the strength and mechanism of any density dependence operating in the population.

Eggs found lying out of burrows are thought to represent failed pair bonds or disrupted breeding attempts of most probably inexperienced breeders (Richdale 1963, Serventy 1967). Frequency of these surface eggs in colonies of different size and burrow density will be counted as a potential index of density dependence in action.

Reviews of density dependence in seabirds (Ashmole 1963, Lack 1966, Birkhead & Furness 1985; Croxall & Rotheray 1991, Wooller *et al.* 1992, Warham 1996) will be updated to identify likely mechanisms affecting tītī recruitment and survival.

Harvest rate per unit effort as a relative index of population density
Our research objective 3 includes a quest to develop reliable population monitoring methods. Use of burrowscopes is proving very expensive, time-consuming and requires highly skilled field staff to do well (Hamilton *et al.* 1997a, 1998; Lyver *et al.* 1998). It is hoped that the harvest rate can act as a linear and robust relative index of abundance that can be used by the muttonbirders to track long-term changes in tītī numbers. If so it may become the key monitoring method to guide an adaptive management approach to testing our first predictions of harvest impacts.

It is very important that we check whether the relationship is linear or curvilinear because this will affect the ability of the index to detect population fluctuations, i.e. if the relationship is curvilinear and the population density is around 'A' in the "scenario" depicted in Fig. 8, a population decline will not be reflected in a decline in harvest rate. But if the population density is around 'B' a rapid decline in harvest rate may be noticed (long after a large density decline has occurred). No such complications arise if harvest rate is directly proportional to chick density (i.e. if the relationship is linear).

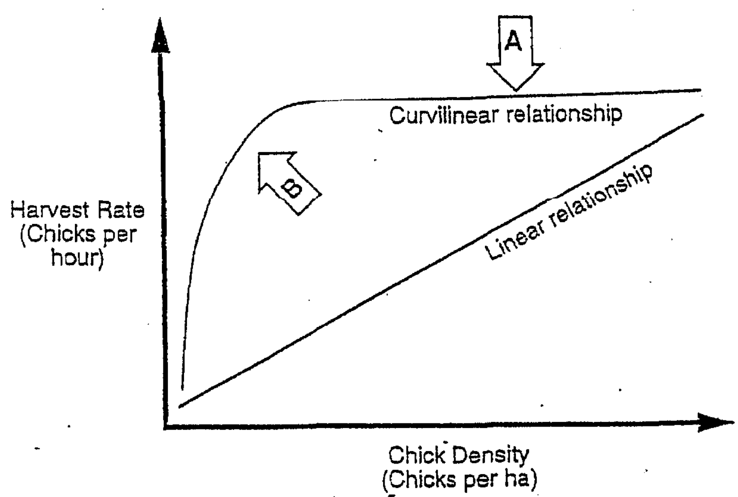


Figure 8: Hypothetical scenarios in the relationship between harvest rate and population density.

Campbell, D. J. 1967. *The Trio Islands, Marlborough Sounds: An ecological study of a bird modified island.* MSc thesis, Victoria University, Wellington. 216 pp.

Cole, R. G.; Singleton, R. J. 1996. Monitoring of Reef Fish Populations at Kapiti Island During Aerial Poisoning for Rats 1996. National Institute of Water and Atmospheric Research, P O Box 893, Nelson (an Unpublished Report Prepared for Wellington Conservancy, Department of Conservation, Wellington).

Colvin, B. A.; Jackson W. B.; Hegdal, P. L. 1991. Secondary Poisoning Hazards Associated with Rodenticide Use. In Magallona, E. D. (Ed). In Proceedings International Congress on Plant Protection 11: 60-64.

Croxall, J. 1984. Seabirds. *Antarctic Ecology*. R. Laws. London, Academic Press: 505.

Croxall, J.; Gaston, A. 1988. Patterns of reproduction in high-latitude northern and southern hemisphere seabirds. *Acta XIX Congr. Int. Orn.* 1: 1176-1187.

Department of Conservation, 1996. Application for Resource Consent Application of Anticoagulant Toxic Baits for Rat Eradication (Kapiti Island): Background Information and Assessment of Effects, Wellington Conservancy, Department of Conservation, New Zealand.

Eason, C. T. 1992. Questions on brodifacoum. *Conservation Advisory Science Notes* No. 2. Department of Conservation, Wellington.

Eason, C. T.; Spurr, E. B. 1995. Review of the toxicity and impacts of brodifacoum on non-targeted wildlife in New Zealand. *New Zealand Journal of Zoology* 22: 371-379.

The birder's success rate is measured in birds captured per hour and the burrow entrance density and occupancy assessed within a 5-10 m radius area where (usually 20) entrance holes have been prospected during the nanao. We conduct follow-up inspections of the burrows prospected for chicks to determine "miss rate" of the birder. Measures of vegetation type and tree basal area are done at each site surveyed in this manner so that the influence of habitat and chick density on success rate can be tested. Whenever possible individual muttonbirders are observed once or twice a week throughout the season and their success rate is assessed at two well-spaced (>100m) sites on each day. This will enable us to describe the mathematical relationship between burrow entrance density and occupancy and harvest rates.

Researchers can not accompany muttonbirders during the rama because their lights may frighten the chicks back into burrows. Therefore, we can only gather an overall measure of harvest rate for a given night from a tally of the harvest and the time taken to gather the birds. We will estimate the density of active (above-ground) chicks on successive nights of the rama from: (a) the proportion of the time spent by radio-tracked chicks out of holes; (b) the proportion of the radio-tagged chicks that have left the island; and (c) combining these two parameters with the pre-rama chick density estimates from transects. At the beginning of the rama there are relatively few chicks active above ground. Later there is a flush of birds, and then a decline as most of the chicks have left the island (Lyver, subm. a). Combining the patterns observed during the early, mid and late rama periods within years, and poor and good chick years, should give strong statistical power to discern the shape of the relationship between harvest rate and bird density during the rama.

Detecting chick presence from cheeping responses

Initial trials of detecting chick presence from cheeping response to acoustic signals suggested that the method would be unreliable (Hamilton 1998a). However, a scratching sound at the entrance of the burrow at dusk during early April 1998 often elicited a cheeping response from the chick within. This response waned dramatically by late April (H. Moller, unpubl.), so obviously it could only be used at certain times of the season. It potentially will vary between years at the same stage of the season if the response is exacerbated by chick hunger.

A systematic study of the cheeping response was therefore mounted in the 1998/99 season. If the method proves to be robust enough to measure chick occupancy, it will have several advantages over the burrowscope. Thirty burrows can be assessed by one observer in the same time that it takes a pair of burrowscope operators to check one burrow, and there is no need for expensive equipment that is prone to breakage. Rakiura Māori could then use the method for the long-term population monitoring after this research project is completed.

Banding at other areas

The main purpose of banding is to measure survival and reproductive rates, but mass banding of birds on our study islands, when combined with the large number of muttonbirders working on the Tītī Islands, also offers the prospect of detecting recruitment of young elsewhere from where they are hatched. Also the dates and locations of dead banded recoveries will allow us to discern the general path and timing of migration of the different age groups of birds, and the range of causes of death. The latter proffer a decidedly non-random sample selection of causes of death, but they might indicate where to intensify study and reconnaissance.

Some muttonbirders offered to band birds on their manu. They were instructed how to band and 172 and 50 chicks were subsequently banded on Taukihepa and Solomon Island (Table 1). Similar banding occurred on Kundy Island in the 1999 harvest season. We will encourage further such efforts as part of a "Participatory Action Research" approach (Wisner *et al*. 1991).

WHAT SETS THE LIMIT ON HARVESTS? (OBJECTIVE 4): RATIONALE AND METHODS

One view holds that Indigenous People's harvest management style is very passive compared to that of eurocentric wildlife management styles using ecological science (Diamond 1992). This leads to the belief that ecological outcomes (species persistence cf. extinction caused by overharvest) in the past are merely historical accidents based on whether the technology used allowed harvesting at a rate faster than the prey populations could withstand or not. A contrary view is that Indigenous People have possessed a TEK and environmentally empathetic philosophy to maintain harvests within sustainable limits irrespective of the technology available to harvest the prey (IUCN 1997). Certainly the concepts of kaitiakitanga safeguard persistence provided that (i) declines in the resource are detected, (ii) *manawhenua* have control of access to the resource, and (iii) manawhenua will act retrospectively to impose a rahui when the resource is depleted (Hodges 1994, Moller 1996).

In the absence of pre-emptive management limits on the number of tītī that may be harvested, the number and proportion of chicks taken will be determined partly by the number of muttonbirders working and how hard they work, and partly by the rate at which they are able to gather and process the birds. Muttonbirders are innovators. They have introduced several new methods this century, such as the use of automated pluckers and wax to remove pin feathers. We need to understand past harvest pressure in order to link them to tītī population trends over the past 30 - 40 years. Therefore we will put considerable emphasis on recording how harvest methods have changed and measuring how these innovations may have altered the number of chicks taken. Further innovations are inevitable, so it is important that we measure the time required for each of the stages of catching and processing birds using current methods. A small amount of extra research of any proposed new methodologies could then be done by Rakiura Māori managers of the harvest to learn whether the changes will increase or decrease the harvest pressure on the tītī populations, and whether such changes are likely to make the new take unsustainable.

Taped interviews and questionnaires will be used to discern why muttonbirders decide when to stop their harvest for the day or night. For example, do they have a target for the number of chicks taken, and if so, why do they choose that target? If population density were to decline, when would they give up harvesting the resource?

Direct observation of muttonbirders at work will pinpoint which tasks mainly determine the time taken to process the chicks (i.e. pluck, wax, dewax, clean, cut up, salt and pack). We will measure whether time remains for birders to increase their overall take, or whether their current take is the maximum physically possible in an exhausting daily routine. This will be achieved by measures of the time taken by Putauhinu muttonbirders in each of the primary tasks (gathering/capturing, processing), and the overall activity of the muttonbirders spent in their routines (work, rest, maintenance activities, etc.).

Muttonbirders' routines in a kiaka year are quite different from those in a good chick year (Phil Lyver and Jane Kitson, unpubl. data). We already have measures for two moderate years on Poutama Island; and one moderately poor year (1997) and two good years (1998 and 1999) on Putauhinu Island. We propose to repeat the measures in one other food failure year, if one appears by the 2004 season.

Comparisons of rates of plucking by hand cf. machine plucking are nearly complete. A potentially important change in processing rate was introduced in the mid 1960s when wax began to be used to clean the fine feathers off the chicks. Before then the birds were "hand-cleaned" after dipping them in scalding water (Richdale 1946, Beattie 1994). One birder still hand-cleans regularly, so we will try to observe his rate of processing, and/or we will request that a few muttonbirders retry the old method briefly to allow comparison of rates.

A review of the historical records and interviews will also focus on whether overall harvest and process rates are now faster. This will help corroborate other inferences of changes in population numbers, assuming that we are able to discern the shape of mathematical relationship between harvest rate and density (as in Fig. 8).

WHAT DO TĪTĪ EAT? (OBJECTIVE 5) RATIONALE & METHODS

The value of a broad description of diet

From the outset the kaitiaki emphasised the need to know what the birds eat (Objective 5). Accordingly we have collected regurgitates from adults handled while being banded and "spews" from harvested chicks over the past 4 years. Muttonbirders "spew" their newly caught chicks by massaging the proventriculus to expel stomach contents (this prevents leaking oils from fouling feathers which otherwise would prevent clean plucking). Muttonbirders have co-operated to spew their chicks into containers for us to freeze and examine in the laboratory over the non-field season. Their contents have been sorted and identified, and three preliminary papers describing these findings are in a late stage of preparation (Appendix 5).

We can identify the potential importance of feeding zones and a broad outline of movement patterns from the identity of the food items in tītī guts. For example, nearly all the diet items identified so far are of species found in inshore northern waters around the southern New Zealand mainland. There was however one squid beak from a species which only known to exist in the Antarctic waters, so it is certain that some birds from the Rakiura Islands at least occasionally visit Antarctic seas, as do short-tailed shearwaters from Australia (Nichols *et al.* 1998). Some of the prey items came from very large items, so it is clear that tītī scavenge as well as taking smaller items whole. This suggests that investigation of titi's use of fisheries wastes warrants further investigation. The description of diet also allows us to focus our upcoming review of fishery impacts on tītī food species.

Using spew samples from harvested chicks has several disadvantages, including the pre-digested nature of their contents, low food volumes, and the fact that such samples are only available in the late breeding season and from harvested islands. If funding can be obtained and more diet samples are deemed a high priority, we will seek to use seawater to off-load stomach contents of live birds that are then released. This method has been used extensively with seabirds to avoid inflicting mortality when obtaining diet samples (Duffy & Jackson 1986). The accuracy of this stomach flushing technique for assessing diet composition has been validated with three species of penguins (Gales 1987). Mike Imber, New Zealand Department of Conservation, has used the method successfully to obtain Procellariid diet samples from Pitcairn Island (pers. comm.). Nevertheless, we will need to first test the method and the kaitiaki have insisted that if the technique is used, there must be a check for effects on survival and breeding success of adults and growth of chicks, respectively.

Do we need more diet studies?

Funding short-falls have prevented our sorting and identifying the food remains in the samples collected from the 1999 season onwards, but at the request of the kaitiaki these samples will be stored, potentially for eventual sorting and identification if the funding situation improves. The separation of the food materials and identification of the remains is enormously time consuming and specialised work. About half a year of work from a post-doctoral follow, 6 months assistance from a laboratory technician, and several weeks work from 3 marine biologists to identify the remains was needed to process ca 200 samples analysed in our preliminary description of tītī diet.

After a broad description of diet is achieved, relatively little new information will be obtained other than on intra-seasonal and inter-annual shifts in diet. This added level of information is nice to have, but the dilemma is that there are relatively little other data available on fluctuations in the abundance and availability of the prey populations against which to interpret such fluctuations. The research team is very pressed to deliver answers to the main population dynamics and demography questions within the first 10 years. Accordingly we urge that further diet samples be only done at the very end of the study, and then only if the central population ecology data have been gathered and fully analysed.

NON-HARVEST IMPACTS ON TĪTĪ POPULATIONS (OBJECTIVE 6): RATIONALE & METHODS

The potential importance of fishery bycatch

Sooty shearwaters are apparently at little risk from bycatch by blue-fin tuna longlining vessels in New Zealand waters (Murray *et al.* 1993), but moderate numbers are killed in by the subantarctic squid trawl fishery (Bartle 1991). However bycatch of tītī in the Northern hemisphere is common (Ainley *et al.* 1981, King 1984, Ogi 1984, Tennyson 1990, DeGange *et al.* 1993). Once the team has completed its extensive survey of tītī colonies, it will be possible to scale this level of artificial mortality against the total number of sooty shearwaters at risk. Fisheries bycatch will soon be reviewed in more detail for our project by Sebastian Uhlmann, a MSc student, who will (i) summarise published data from north and southern hemispheres, (ii) network to see whether unpublished data exist that can be analysed and peer reviewed, (iii) attempt to develop robust statistical limits on estimated number of deaths, (iv) review potential mitigation methods (e.g. Barnes & Walshe 1997), and (v) request discussions with the Department of Conservation, the MAFish Scientific Observers Program, and fishing boat owners to find ways of reducing the bycatch threat to sooty shearwaters in New Zealand waters.

If further investigation seems warranted, we will request permission to analyse existing data and solicit co-operation from MFish to trial targeted observations on-board large trawlers and long-liners. We will calculate the statistical power of the measures of Sooty Shearwater bycatch frequency, and determine bounds on the maximum and minimum proportion of adults being killed annually in New Zealand waters.

Fishery impacts on tītī foods

Many muttonbirders have expressed concern to the research team that fishing may be reducing food supplies for tītī. Interactions between fisheries and food species are probably very complex, and certainly very difficult to study. Scavenging of fishery wastes may even sometimes increase bird numbers (Furness *et al.* 1988, Freeman 1997). Similarly, we hypothesise that lights of squid boots may increase the foraging success of tītī. Our first priority to meet Objective 6 will be to assess the bycatch threat because at least there is a *prima facie* case that the threat exists. We will intensify study of potential food/fisheries interactions in the later stages of the *Kia Mau Te Tītī Mo Ake Tōnu Atu* research project if resources allow. Review of potential bycatch mitigation methods (e.g. Barnes & Walshe 1997) will be included.

The importance of climate fluctuations

Our most recent research has already identified declines in tītī abundance in the years preceding El Niño events over the past 19 years (Lyver et al. in press). Counts of tītī off the USA coast declined by 90% between 1987 and 1994 and may be linked to increased sea surface temperatures there (Veit *et al.* 1996, 1997). The Veit et al. findings may partly reflect distributional changes, but our analysis of a muttonbirder's harvest diary has corroborated their inference of a rapid decline since 1989. However, the diary also showed that the tītī are in some way affected by the precursor climate conditions that bring El Niños or La Niña weather conditions, because fluctuations in tītī harvest rate predict the weather pattern ensuing over the next year (Lyver et al. in press). It appears that adult survival is impaired greatly when an intense El Niño is coming, perhaps because food availability or feeding efficiency are impaired, or perhaps because changed wind patterns make migration back to the southern hemisphere more difficult. A role for local weather impacts on early breeding behaviour and success can not be ruled out.

We will now use newspaper reports, past notes of naturalists and researchers, and birder diaries to test whether the same correlations occurred early in this century (El Niño climate fluctuation records are available back until 1876; Allan *et al.* 1996). If the correlation holds, a new mathematical model will be developed to simulate tītī population trends over the past 120 years. A literature review will then examine the relationship, if any, between predicted world climate change and the future intensity and duration of El Niño events. If such links seem likely, a further simulation model will predict future tītī abundance and harvests according to plausible world climate change projections.

Pollutants

Accumulation of plastic within bird guts threatens some northern seabirds (Furness 1985 a, b). Therefore we have analysed ingested plastic fragments (Cruz *et al.* in prep.) as the first step in an overall assessment of pollutant threats to sooty shearwaters (Objective 6).

Carcasses of tītī killed by fishing lines or nets in New Zealand waters are gathered by the DoC for determination of their breeding status and condition (CJ Robertson, pers. comm.). The carcasses will be given to our research team after DoC's necropsy is complete. We hope to gain funds to analyse their tissues for heavy metal and pesticide levels for a preliminary risk assessment from these pollutants.

MĀTAURANGA AND KAITIAKITANGA (OBJECTIVE 7)

Kaitiakitanga, Mātauranga Māori and Traditional Environmental Knowledge

The traditional Environmental Knowledge of Māori, Mātauranga Māori, is a mixture of spiritual and natural history observations gleaned over centuries of living and working in the environment. In the tītī harvest case it embodies accumulated understandings of the seasonal patterns of the birds' behaviour, movements, growth, feeding, chick care, fledging behaviour, annual variation in abundance and fatness, and spatial variation in abundance and harvestability (and several other aspects of biology and ecology). Knowledge on how to collect, process and preserve the birds is included. Understanding of the behaviour and potential impacts of the harvesters is part and parcel of the overall management of the resource within an overall umbrella of kaitiakitanga. Intermingled with the specific knowledge of the birds and the islands will be an underlying environmental philosophy and tikanga that forms part of Mātauranga.

Recording Mātauranga
An important first step for the research is to record the TEK of the harvesters. We will then choose a subsample of TEK constructs for detailed scientific study so that we can compare the strengths and weaknesses of each knowledge system.

Like most Indigenous People's traditions and knowledge, they are orally transmitted and learnt by participation. The initial approach will be to tape record interviews (3+ hours each) with 20 experienced tītī harvesters. Jane Kitson has been trained in interview techniques and is conducting them as part of her PhD research (1998 - 2001).

Tape copies are given back to the interviewees and release of the information or black-out of specific sections can be prescribed by the interviewee according to normal ethical practice and our study permit from the University of Otāgo.

The initial interview sample will be *kaumātua*, primarily out of respect for their *mana*, and their long term relationship with the islands and harvesting practises. This sample will not be a random selection of 'muttonbirders', but past it will provide a valuable source of TEK and past practises, trends and changing values within the birding community. This group will also be interviewed first, so as not to lose this wealth of knowledge.

We seek 'life history' interviews because the birder's life has usually been structured around tītī harvests in matters of cultural identity, seasonal employment and economic factors. Oral histories are an ideal and socially congruent method of gathering historical information from Māori (Royal 1992). These life histories themselves will also prove to be a valuable taoka for future generations to learn from, quite apart from the mātauranga revealed about tītī.

Initial interviews will include open ended questioning concerning kaitiakitanga (its place in present day, attitudes to current conservation practises, rahui etc.), and specific issues of bird numbers, behaviour, bird condition, variation between years, long term trends. These questions will be developed from informal discussions on Poutama, Putauhinu, and at the Permit Day gathering.

The heterogeneity of practices and traditions on different islands will be addressed by interviewing representatives of many different families. The interviewees would have practised the more 'traditional' methods (i.e. use of pōhā and fat for preserving) and witnessed the introduction of more 'modern' processing technologies (e.g. salt, plastic buckets, plucking machines).

We will also conduct a workshop for Rakiura Māori and other Māori and Pakeha wildlife managers to place the results of the interviews with tītī harvesters in a wider context of other natural resource management practices by Māori and Pakeha. This hui is scheduled for mid to late 2000. The discussion will be recorded and a proceedings published from it.

The initial 20 detailed interviews and the discussions at the hui will then be analysed to structure a more specific questionnaire, with a mixture of closed questions and open ones centring on identified themes and hypotheses. Questionnaires will first be tested on a subsample of harvesters to check if the results are interpretable.

Once this questionnaire is finalised an additional 20 current tītī harvesters will be interviewed using the questionnaire to structure the discussion. Interviewees for this part of the study will be chosen by stratified random sampling means from the *Tītī Times* mailing list to ensure that gender and age groups